OIPE JC76
JUL 0 5 2001
PATENT & TRADEMARK OFFICE

1111.64360

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-5-01
Date

Express Mail No.EL 846162315 US

RECEIVED
JUL 3 1 2001
Technology Center 2600

RECEIVED
JUL 1 1 2001
OFFICE OF PETITIONS

Repln. Ref: 03/06/2002 AKELLEY 0014233900
DAH:072069 Name/Number:09581468
FC: 704 $390.00 CR

PETITION TO REINSTATE PROCEEDINGS AND GRANT FILING DATE PURSUANT TO 37 C.F.R. § 1.181(f), PETITION TO WITHDRAW AND REISSUE NOTICE, RESETTING RESPONSE TIME, PURSUANT TO 37 C.F.R. § 1.182, AND PETITION FOR SUSPENSION OF RULES PURSUANT TO 37 C.F.R. § 1.183

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

RECEIVED
DEC 1 8 2001
OFFICE OF PETITIONS

Adjustment date: 03/06/2002 AKELLEY
07/10/2001 GTEFFERA 00000134 09581468
01 FC:122 -390.00 OP

POINTS TO BE REVIEWED AND ACTION REQUESTED

Applicants petition for reversal of an April 3, 2001 action of the Office of Initial Patent Examination (OIPE), denying applicants a June 12, 2000 filing date on the basis that the entire specification and all of the drawings were allegedly not filed on June 12, 2000. Though this petition is being filed more than 2 months after the date of the April 3, 2001 Notice, Applicants respectfully request that this petition not be dismissed as

07/10/2001 GTEFFERA 00000134 09581468
01 FC:122 390.00 OP

03/06/2002 AKELLEY 00000018 072069 09581468
01 FC:115 [illegible]0.00

untimely, that these proceedings be reinstated, and that the above-referenced application be accorded a June 12, 2000 filing date, pursuant to Rule 181(f). In the alternative, applicants petition that the April 3, 2001 Notice be withdrawn, because it is clearly erroneous, and that a corrected Notice be issued, with a two month time for response, pursuant to Rule 182. As an additional basis for granting the relief sought, applicants petition that the rules be suspended to consider this petition, reinstate prosecution proceedings, and grant applicants a June 12, 2000 filing date, pursuant to Rule 183.

The grounds for this petition are that the entire specification and drawings were properly filed on June 12, 2000, entitling applicants to a June 12, 2000 filing date for this application, subject only to filing missing parts. This petition should not be dismissed as untimely because statements by the PTO, including the OIPE, were a primary contributor to applicants' failure to file this petition within two months. The petition should also not be dismissed because all of the drawings were discovered in (and surely always were in) the U.S. Patent and Trademark Office (PTO) file for this application, so the Notice was clearly erroneous *ab initio* and should be withdrawn pursuant to Rule 182, which is not subject to the two month time for response found in Rule 181(f). Because the June 12, 2000 filing date is needed for priority and priority must be preserved to avoid a loss of rights, justice requires that this petition not be dismissed as untimely pursuant to Rule 181, that prosecution proceedings be reinstated, and that the Rules be suspended pursuant to Rule 183, if necessary, to reinstate the proceedings and grant applicants a June 12, 2000 filing date.

EVIDENCE AND OTHER PAPERS ACCOMPANYING THIS PETITION

The following declarations and other papers are enclosed with a transmittal letter and return postcard receipt:

1. Declaration of Jonathan D. Feuchtwang, the attorney who filed the application, with

(a) a copy of the express mail receipt for this application showing receipt by the U.S. Postal Service on June 12, 2000 and a weight of 2 lbs., 6.4 oz. (Exh. A),

(b) a copy of the postcard receipt for this application, acknowledging receipt of the entire specification and all of the drawings in the PTO as of June 12, 2000 (Exh. B), and

(c) a photocopy of the specification and drawings filed on June 12, 2000 (Exh. C).

2. Declaration of Terry Kannofsky, who copied the drawings from the PTO file, with a photocopy of the drawings and some other papers (page numbers TK-1 through TK-39 have been added) found in the PTO's file for this application.

3. Declaration of Eura Goard, describing her frustration with the PTO's handling of this application and her instructions regarding the April 3, 2001 Notice.

4. Declaration of John Pionke, describing statements made by the PTO that the filing receipt had been mailed, and statements made by the OIPE that the Notice of Incomplete Application should have been a Notice of Missing Parts.

5. Declaration of Sidney Bell regarding an inadvertent docketing error.

6. Declaration of Patrick G. Burns, describing parts of his investigation of this matter and explaining that applicants' failure to respond to the Notice by June 4, 2001 was inadvertent and unintentional.

7. A declaration and power of attorney signed by the named inventors of the present application.

8. The basic filing fee of $1,398.00.

9. The fees for these petitions in the amount of $390.00.

10. A petition for extension of time to file missing parts, with a check for $110.00, and a conditional petition for extension of time in the event that the time for filing this entire petition may be so extended.

STATEMENT OF FACTS AND ARGUMENT

The Specification And Drawings Were Timely Filed On June 12, 2000

This application was filed on June 12, 2000, as a continuation of a PCT application filed in Japan on October 8, 1999. Priority is also based on two Japanese applications, the first having been filed on October 12, 1998. June 12, 2000 is within twenty months of the earliest priority date claimed. Without priority, however, patent rights will be lost.

In filing the application, Jonathan Feuchtwang followed his usual practice of personally reviewing the application papers when they were ready to be filed,

personally placing the application in a properly addressed envelope, sealing the envelope and delivering it to the person who signed the certificate of express mailing (Feuchtwang Dec., ¶3). For this reason, he testified that the papers filed with this application on June 12, 2000 included 67 pages of specification, claims and an abstract, as well as 25 sheets of formal drawings (Feuchtwang Dec., ¶5). The actual specification and drawings filed with this application are attached as Exh. C to the Feuchtwang Declaration.

The Feuchtwang Declaration is supported by the express mail receipt for this application, attached as Exhibit A to the Feuchtwang Declaration. Consistent with the expected weight of 67 pages of specification, claims and an abstract and 25 sheets of drawings, as well as other related papers, the receipt indicates that the package mailed on June 12, 2000 weighed 2 lbs., 6.4 oz. In investigating this matter, Patrick Burns compiled the papers filed by Mr. Feuchtwang and weighed them. He then removed the specification, drawings and Preliminary Amendment papers the Scanning Department did not find (as seen in TK-39 to the Kannofsky Declaration), and confirmed that the weight measured by the Postal Service is consistent with the weight of a package that included the specification, drawings and preliminary amendment (Burns Dec., ¶7).

The Feuchtwang Declaration is further supported by the postcard receipt for this application, attached as Exhibit B to the Feuchtwang Declaration. Exhibit B is *prima facie* evidence of receipt of 67 pages of specification, claims and an abstract, as well as

25 sheets of formal drawings.[1] Surely, the absence of the entire specification and drawings would have been noticed when receipt was acknowledged on the postcard, and the postcard would have so indicated.

Compelling evidence that the application was properly filed on June 12, 2000 is found in the Kannofsky Declaration. Among other things, she found all the drawings for this application in the PTO file (TK-13 through TK-38), identified by the serial number of this application. She also found the preliminary amendment in the file (TK-9 through TK-12). Thus, though the document generated by the PTO (TK-39) indicates that the specification, drawings and preliminary amendment were missing, at least the drawings and preliminary amendment were clearly in the file. This evidence further establishes that the application was properly filed on June 12, 2000, and that while the PTO apparently misplaced the specification, the other supposedly missing documents were simply not found in the file.

Moreover, the application was filed on June 12, 2000 and the OIPE did nothing until April 3, 2001, and only acted then after applicants' representative inquired about the status of the application several times (Pionke Dec). The postcard receipt suggests that the application papers were initially sent to the PCT branch, not the OIPE. The specification could easily have been misplaced in this confusion, and applicants should not be penalized as a result. For all of these reasons, this petition should be

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1 It also acknowledges receipt of the Preliminary Amendment filed with this application, which was not found when the application was reviewed for scanning (TK-39).

granted, and the specification attached as Exh. C. to the Feuchtwang Declaration should be placed in the file and used to prosecute the application.

This Petition Should Not Be Dismissed As
Untimely, And Prosecution Should Be Reinstated

The April 3, 2001 Notice set a two month response date, pursuant to 37 C.F.R. § 1.53(e). Rule 53(e)(3) acknowledges that petitions can be filed under Rule 181(f), which provides that a petition not filed within two months from the action complained of **may** be dismissed as untimely. Thus, while the Rule apparently does not allow for automatic extensions of time,[2] the Commissioner clearly has discretion with respect to dismissal of a petition filed after two months. *Helfgott & Karas v. Dickinson,* 54 USPQ2d 1425 (Fed. Cir. 2000). Applicants urge that discretion should be exercised in applicants' favor in this case, in the interest of fairness and justice.

The Notice of Incomplete Application mailed on April 3, 2001 is clearly erroneous, and was clearly erroneous when sent. The Notice finds that the drawings were not filed, but Terry Kannofsky found the drawings in the application file (Kannofsky Dec., ¶2). The Notice is clearly erroneous, at least to that extent, and this was an obvious error that could and should have been corrected before the Notice was sent. In fact, it should be corrected now by withdrawing the April 3, 2001 Notice and issuing a corrected

[2] If for any reason extensions of time may be obtained automatically with respect to this Notice, applicants request such an extension. A Conditional Petition for Extension of Time, with authorization to charge the extension fee to Deposit Acct. 07-2069, is enclosed.

Notice setting a two month time for response.[3] The oversight by the PTO should not deprive applicants of their patent rights, even if applicants' representatives are partially at fault. *See, Helfgott, supra.*

When the Notice was received by the firm of applicants' representatives, Greer, Burns & Crain, Ltd. (GBC), it was given to the docketing department with the file (Bell Dec., ¶3). While the docketing process was started, it was inadvertently not completed. As a result, the response date did not appear on docketing calendars.

Notwithstanding the lapse in docketing, immediate action was taken with respect to the Notice. A copy of the Notice was given to Eura Goard, the office manager at GBC and she immediately assigned John Pionke, a GBC law clerk, to investigate. Her frustration with errors of the PTO in similar circumstances, and her frustration with this application due to several previous inquiries by Mr. Pionke, in which he understood that the filing receipt had been sent, caused the frustration reflected in her instructions.

> "John, please call PTO about this crazy case. See your note in file. Eura".

Goard Dec., ¶4, Goard Exh. A.

After receiving these instructions, Mr. Pionke made several inquiries to the OIPE, in a good faith effort to resolve this matter expeditiously and without expending unnecessary resources (Pionke Dec., ¶4-5). He believed that the Notice had been sent in error, in part because he had made previous inquiries about this application on December

---

[3] This petition for relief is made pursuant to Rule 182, which is not subject to the two month time frame of Rule 181(f). *Helfgott, supra*, 45 USPQ2d at 1428, n. 3. Applicants submit that Rule 183 is also not subject to the time frame of Rule 181(f).

12, 2000, January 16, 2001 and March 21, 2001 (Pionke Dec. ¶3), and had been told by the PTO representatives that the filing receipt had been mailed.

When asked to inquire about the April 3, 2001 Notice, Mr. Pionke spoke with a representative of the OIPE, who told Mr. Pionke that he was probably correct in believing that the Notice had been sent in error (Pionke Dec.,¶4). The OIPE representative kindly agreed to find the file from central files and call him back, which he appreciated and accepted in good faith. If he had been told that the Notice was correct, and that a petition would be required, he would have considered his assignment complete and reported to the office manager or an attorney (Pionke Dec., ¶6).

Mr. Pionke followed-up with another call on May 14, 2001, and was told again that the file would be ordered and he would be called back. He called again on May 15, 2001 (Pionke Dec., ¶5).

The file was then taken from his office, probably to file a routine IDS (filed on May 30, 2001), and the file was not returned to him. The PTO's misstatements and inactions, though presumably in good faith, misled Mr. Pionke to believe that the Notice would be expeditiously withdrawn *sua sponte,* or his call would be returned and his request for assistance refused.

Applicants respectfully submit that the PTO was a primary contributor to the delay in filing these papers. But for Ms. Goard's past experience with similar notices, and the PTO's repeated representations that the filing receipt for this application had been sent, Ms. Goard and Mr. Pionke would not have been so skeptical of the April 3, 2001 Notice, and the file would likely have been given to an attorney immediately for action,

irrespective of whether the June 4, 2001 date had been entered in the docket. Indeed, but for these PTO actions, the file would probably not have been given to Mr. Pionke as abruptly as it apparently was, and perhaps the docketing error would not have occurred. But for the representations of the PTO that the Notice probably was in error and that the file would be found and reviewed by the PTO, Mr. Pionke would have given the file to an attorney, or returned it to the Office Manager (Pionke Dec., ¶6), who would then have given the file to an attorney (Goard Dec., ¶5).

The failure of the PTO to find the drawings in the file when the Notice was issued, the PTO's repeated erroneous statements that the filing receipt had been mailed, and the PTO's statements to the effect that the April 3, 2001 Notice probably should have been a Notice to File Missing Parts are circumstances which require the exercise of discretion by the Commissioner, where, as here, the failure to reply within two months was unintentional and due to inadvertent error. As the Federal Circuit said in *Helfgott*:

> Helfgott argues that while it bears no small amount of blame for the circumstances, the Commissioner was also a primary contributor, and should have accordingly exercised his discretion in this situation. We agree.

Helfgott, *supra*, 54 USPQ2d at 1431. Under these circumstances, the Commissioner should exercise his discretion in applicants' favor, notwithstanding an inadvertent error or errors by applicants' representatives.

While it could be argued that one talks to PTO representatives at his/her risk, the better rule is that PTO representatives must make reasonable efforts to at least review files, give accurate information and return phone calls when they state that they

will do so. It may be unreasonable to expect PTO personnel to be experts on the law or even some PTO procedures, but it is not unreasonable to expect that accurate information will be given, calls will be returned and promised actions performed. PTO personnel should not be discouraged from being helpful and should not be penalized for inadvertent errors, but applicants also should not be penalized for such errors, particularly where, as here, applicants' representatives made a conscientious effort to advance prosecution by bringing these problems to the attention of the PTO to have them resolved expeditiously. While a more experienced person might have been skeptical of the PTO's repeated statements about the filing receipt, and its commitment to obtain the file and return Mr. Pionke's calls, applicants should not be penalized because Mr. Pionke was unaware of the likelihood that misinformation might be given and inadvertent errors would be made.[4]

Strict adherence to the two month period is not justified in this case, as it might be under other circumstances described in M.P.E.P. § 601.01(d). This application has not been forwarded for examination. According the June 12, 2000 filing date will only cause the patent to expire earlier than it would if the case were re-filed now, and filing a CIP or continuation application is not possible now in any event because priority cannot be claimed and priority is needed to avoid the loss of patent rights. Moreover, accepting this petition such a short time after the two month period will not adversely

4 Applicants are not suggesting that the PTO representatives Mr. Pionke talked to have a practice of not returning phone calls and so forth. Indeed, the PTO, and particularly the OIPE personnel, appear to be overworked and inundated by inquiries, yet make every reasonable effort to be patient, courteous and helpful. Applicants' point is that applicants should not be penalized by such errors, and the Commissioner's policy should encourage PTO personnel give accurate information, return calls and to follow through with commitments, even on the telephone.

affect the functioning of the patent system. In fact, not reinstating prosecution will prevent publication in the U.S., which will adversely affect the patent system.

Applicants respectfully request that all of these circumstances be considered. Weighed against the loss of patent rights applicants will suffer if this petition is not considered and granted, these circumstances are compelling. Applicants urge the Commissioner to exercise the discretion permitted by Rule 181(f) and Rule 183, and consider this petition after the two month period, or to reissue the Notice and set an additional time for response.

Conclusion

For the foregoing reasons, applicants pray that this petition be considered and granted in its entirety, and that applicants be granted a June 12, 2000 filing date, or that the Notice be withdrawn, corrected and reissued with a two month time for response. Applicants request a refund of any fees found to be unnecessary.

Respectfully submitted,

GREER, BURNS & CRAIN, LTD.

By

Patrick G. Burns
Registration No. 29,367

July 5, 2001

300 South Wacker Drive
Suite 2500
Chicago, Illinois 60606
Telephone: 312.360.0080
Facsimile: 312.360.9315
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JUL 1 1 2001
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JUL 0 5 2001

1111.64360 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-5-01 — *Date*

Express Mail No. EL 846162315 US

DECLARATION OF JOHN PIONKE

RECEIVED
JUL 1 1 2001
OFFICE OF PETITIONS

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

John Pionke declares:

1. I am a 2001 graduate of The John Marshall Law School, and I am employed as a Law Clerk by Greer, Burns & Crain, Ltd. ("GBC"). I have been employed by GBC since November 2000.

2. My duties at GBC include making periodic status checks for patent applications, and making other telephonic inquiries to the U.S. Patent and Trademark Office ("PTO").

3. Prior to April 3, 2001, I made inquiries about the status of this application on December 12, 2000 (Exh. A and B), January 16, 2001 (Exh. C and D) and March 21, 2001 (Exh. E), at the request of the docketing department. I was told more than once by agents at the PTO, that the filing receipt had been mailed.

4. Some time after April 11, 2001, I was asked by Eura Goard, the Office Manager at GBC, to inquire about a Notice of Incomplete Nonprovisional Application mailed to GBC in connection with this application, as seen in Exh. F. On April 18, 2001, I spoke with Janice Burse with the Office of Initial Patent Examination ("OIPE"). I told Ms. Burse that I believed we had received the Notice of Incomplete Nonprovisional Application in error, and that GBC should have received a Notice to File Missing Parts (Exh. F). Ms. Burse left for a few minutes. She then returned and said she believed that I was probably correct according to what she saw on the screen. Ms. Burse then stated that she would have to pull the file from their central files and verify that GBC was correct. Ms. Burse then stated that she would call me back when she received the file and made that verification.

5. I followed-up on May 14, 2001. I was told that OIPE had not received the file and that they would order it and that I should call back the next day. On the following day, May 15, 2001, I called again and received no response. I believe that the file was taken from my office soon thereafter and was not returned.

6. Based on my conversations with the OIPE, I believed that the Notice would be replaced with a Notice to File Missing Parts, or I would be called and told that the April 3, 2001 Notice was correct. Had I been told by the OIPE that the Notice was correctly

sent and a petition would be required, I would have considered the assignment complete and immediately given the file to the Office Manager or an attorney and reported the situation.

7. Exh. A is a true and correct copy of a portion of a docket report generated by the GBC docketing department, with my hand written notes regarding a telephone conference I had with the PTO on December 12, 2000. Exh. B is a true and correct copy of hand written notes that I made with respect to my December 12, 2000 conversation with the PTO regarding the status of this case. Exh. C is a true and correct copy of a portion of another docketing report generated by the GBC docketing department, and includes a summary of my conversation with the PTO regarding this case on January 16, 2001. Exh. D is a true and correct copy of a memorandum I prepared on January 17, 2001, regarding my conversation with the PTO on January 16, 2001. Exh. E is a true and correct copy of a portion of yet another GBC docketing report, with a true and correct copy of a memorandum I prepared summarizing a conversation I had with the OIPE on March 21, 2001. Exh F. is a true and correct copy of an April 3, 2001 Notice of Incomplete Nonprovisional Application directed to this application, with instructions I received from the Office Manager regarding this case, and a true and correct copy of notes I made summarizing conversations with the PTO regarding this application on April 18, 2001, May 14, 2001 and May 15, 2001.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: June 29, 2001

John Pionke

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OFFICE OF PETITIONS

John

12/04/00 Detailed Patent Docket Report Page: 161
Greer, Burns & Crain, Ltd.

\\\\\ 12/12/00 /////

Fax copy of current address 703/308-7751

PGB/JKF 1111.64360 -
Filed: Serial Number:
Issued: Patent Number:
Title:

request to change address

(Client: Kitano & Associates)
Inventor:
Action: US--Status of Filing Receipt?

will fax copy of receipt

Bionke
Exh. A

OIPE JC76
JUL 0 5 2001
PATENT & TRADEMARK OFFICE

RECEIVED
JUL 1 1 2001
OFFICE OF PETITIONS

12/12/00

Spoke w/ cust. srvc. agent

- was told that filing receipt was mailed to Sears Inv.
- Asked them to change address & they told me they need written change rqst
- They will fax filing receipt today

JP

Pjonke
Exh. B

\\\\\ 01/12/01 /////

PGB/JKF 1111.64360 -

Filed:

Issued:

Serial Number:

Patent Number:

Title:

(Client: Kitano & Associates)

Inventor:

Action: US--Status of Filing Receipt? (T/C w/PTO 12/12/00)

John P.

1/16/00 PTO advises sending letter

Pionke

Exh. C

MEMO to file

To: File 1111.64360
From: John Pionke
Subject: Request for Filing Receipt
Date: January 17, 2001

Per docket sheet I contacted the PTO on Jan 16, 2000 and asked them the status of receipt. They told me that they had record of sending. I told them we do not have it. They suggested sending a letter requesting filing receipt. Copy of letter is in file.

Pionke
Exh. D

MEMO to file

To: File
From: John Pionke
Subject: Status check
Date: March 21, 2001

Spoke with the Office of Initial Patent Examination. They told me that this case has been assigned but has not yet been keyed. When it is keyed we will receive all applicable information from Office of Initial Exam and the case will be assigned to an examiner.

DOCKETED
MAR 21 2001
[illegible], BURNS & CRAIN, LTD.

```
PGB/JKF      1111.64360  -        \\\\\ 08/14/00 /////
Filed:                       Serial Number:
Issued:                      Patent Number:
                             Title:

                             (Client: Kitano & Associates)
                             Inventor:
Action: US--Received Notice of Missing Parts?
```

John P.

Pionke
Exh. E

UNITED STATES PATENT AND TRADEMARK OFFICE

COMMISSIONER FOR PATENTS
UNITED STATES PATENT AND TRADEMARK OFFICE
WASHINGTON, D.C. 20231
www.uspto.gov

APPLICATION NUMBER	FILING/RECEIPT DATE	FIRST NAMED APPLICANT	ATTORNEY DOCKET NUMBER
09/581,468	06/12/2000	MASASHIGE SATO	1111.64360

CONFIRMATION NO. 9963
FORMALITIES LETTER

OC000000005930750

PATRICK G BURNS
GREER BURNS & CRAIN
SEARS TOWER SUITE 8660
233 SOUTH WACKER DRIVE
CHICAGO, IL 60606

John, Please call PTO about this crazy case. See your note file

GREER, BURNS & CRAIN, LTD.
01 APR 11 AM 10:35

Date Mailed: 04/03/2001

NOTICE OF INCOMPLETE NONPROVISIONAL APPLICATION

703/308-1202

A filing date ... ers for the reason(s) indicated below.

All of the ite... vering the items must be submitted v... indicated, or proceedings on the application ...

The filing d... therwise indicated. Any assertions that the iten... ing date, must be by way of petition dire... $130.00 petition fee (37 CFR 1.17(h)). If t... request for a refund of the petition fee may be ...

- The ...
- The ... *A co...*
- The ... sentence) requires a drawing "whe... to be patented." *Applicant should reco... (first sentence).*

The require... red above. The filing date of this nonprovisio... ove.

- The ... a small entity statement claiming *Appli... such*
- The ... *A pro... identifying the application by the abov...*
- The ...

Spoke w/ Janice Burse w/ IPE. Told me we should have rcd missing parts according to comp. Told her we rcd Incomplete Nonprovisional. She will order case and inquire further. I asked her to call when she rcs the file.

JP 4/18/01

F/U 5/14/01 - She asked that I call 5/15/01

Called w/ no response

...he reply.

Pionke
Exh. F
(1/2)

R W Brown

Customer Service Center
Initial Patent Examination Division (703) 308-1202

PART 2 - COPY TO BE RETURNED WITH RESPONSE

Pionke
Exh. F
(2/2)

1111:64360 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-5-01

Date

Express Mail No. EL 846162315 US

Art Unit:

Examiner:

DECLARATION OF PATRICK G. BURNS

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

RECEIVED
JUL 1 1 2001
OFFICE OF PETITIONS

Patrick G. Burns declares:

1. I am licensed to practice law in the state of Illinois, and I am registered to practice before the U.S. Patent and Trademark Office ("PTO"). I have primary responsibility for about 600 pending U.S. patent applications, including the above-referenced application. I am assisted by the staff and several attorneys of Greer, Burns & Crain, Ltd., ("GBC").

2. Our office has established procedures for processing papers sent to and received from the PTO in connection with patent application. Among other things, all

documents received from the PTO are date stamped by the mail room, and given to the docketing department with the file. Relevant dates are entered into a computer data base, and the dates entered are independently verified. For applications like the present application, a copy of the document is immediately sent to the client. The file is then given to someone for action, if needed.

3. In the course of prosecution, we often file routine documents, irrespective of other activity in the application. In this case, for example, we filed a Request for a Filing Receipt on January 17, 2001. We faxed a Change of Address on January 10, 2001, and we filed a routine Supplemental Information Disclosure Statement on May 30, 2001.

4. When I file routine documents, I do not always review the entire file. Papers requiring a response are often assigned to another attorney, and I rely on our docketing department for direction regarding responses, etc.

5. On about June 7, 2001, a member of our staff drafted a routine declaration and assignment for filing in this case, in response to an unsolicited request from the client. In reviewing those documents, I saw the Notice of Incomplete Application mailed April 3, 2001, and realized that our firm had not responded to the Notice within the two month deadline set in the Notice. The client had not been informed of the Notice at that time. Soon thereafter, I learned that the document had inadvertently not been docketed in our computer database, and that John Pionke, a member of our staff, had been given the file with

the Notice. I also learned that he contacted the OIPE several times before June 4, 2001, in an effort to resolve the matter expeditiously.

6. In the course of my investigation of this matter, I asked Terry Kannofsky to inspect the file for this application in the PTO. As described in the Declaration of Terry Kannofsky, she found the drawings for this application, among other things.

7. One of the documents found by Terry Kannofsky (TK-39) was apparently prepared by the Scanning Department at the OIPE. That document indicates that the specification, drawings and preliminary amendment were not present for scanning. I reconstructed the papers filed on June 12, 2000 from our file. The entire application, including the specification, drawings and preliminary amendment (but without the envelope), weighed 2 lbs., 8.1 oz. on our office scale, very close to the 2 lbs., 6.4 oz. found in the Express Mail receipt for this application (Exh. A to the Feuchtwang Declaration). I removed the specification, drawings and preliminary amendment, and the remaining documents weighed 1 lb., 7.2 oz. on our office scale. For this and other reasons, I believe that the entire specification, drawings and preliminary amendment were filed with the present application.

8. Our firm's failure to respond to the April 3, 2001 Notice by June 4, 2001 was unintentional, and any errors on our part were inadvertent.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: 28 June 01

Patrick G. Burns

F:\DATA\WP60\1111\64360\burnsdec.DOC

1111.64360 PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR,
MAGNETIC HEAD,
MAGNETIC ENCODER AND
HARD DISK DEVICE

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-5-01 [signature]

Date *Express Mail No. EL 846162315 US*

Art Unit:

Examiner:

DECLARATION OF EURA GOARD

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

Eura Goard declares:

1. I am employed by Greer, Burns & Crain, Ltd. ("GBC"). I have been employed by GBC since June 22, 1995. My present position is Office Manager.

2. I was the Docketing Clerk at GBC from June 22, 1995 to about January 2001, and I am familiar with all docketing procedures at GBC. As Office Manager, I still oversee docketing.

3. I hired Sidney Bell as Docketing Clerk in January 2001, and trained him with respect to docketing procedures. I reviewed all of his work through about the end of March 2001, and I reviewed unusual papers in April 2001.

4. On about April 11, 2001, GBC received a Notice of Incomplete Nonprovisional Application in the above-referenced patent application. When I saw the Notice, I reviewed the file, and saw that John Pionke, a law clerk at GBC, had been told repeatedly that a filing receipt had been sent for this case. I wrote a note to Mr. Pionke, asking him to investigate this case to determine if the Notice was a PTO error and was an appropriate document (Exh. A). I did this in part because GBC periodically receives notices of abandonment and the like that are incorrect and are withdrawn or corrected by the PTO with a phone call. At the time, GBC was expecting a filing receipt and a Notice to File Missing Parts, and I believed that the Notice of Incomplete Nonprovisional Application had been sent in error.

5. If Mr. Pionke had returned the file for this case to me and told me that papers would have to be filed in response to the Notice, I would have immediately given the file to an attorney for action, irrespective of the computer docketing system.

6. Exh. A is a true and correct copy of the Notice received for this patent application, with instructions I gave to John Pionke about the time the Notice was received.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: 6/29/2001

Eura Goard

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1111.64360

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-5-01
Date

Express Mail No. EL 846162315 US

DECLARATION OF SIDNEY BELL

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

Sidney Bell declares:

1. I am employed by Greer, Burns & Crain, Ltd. ("GBC"). My position is Docketing Clerk. I have been employed by GBC since January 18, 2001, and was in training through about the end of March 2001.

2. My duties at GBC include docketing all papers received from the U.S. Patent and Trademark Office ("PTO"), as well as docketing all papers sent to the PTO. I typically process about 50 application files per day.

3. GBC has detailed docketing procedures that include entering due dates for papers to be filed in the PTO, reminders before due dates, status checks, etc.

4. On about April 11, 2001, GBC received a Notice of Incomplete Nonprovisional Application in connection with the above-referenced application. In accordance with normal office procedures, the mail room stamped the date received on the document, associated the document with the file, and delivered the document and file to docketing.

5. I stamped the Notice with a docketing stamp. The document indicated that a response was due within two months of its April 3, 2001 mailing date. I wrote a due date of June 4, 2001 (June 3, 2001 being a Sunday) on the document. However, I inadvertently did not enter the due date in the docketing system. This error was unintentional.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: 6-28-01

Sidney Bell
Sidney Bell

F:\DATA\WP60\1111\64360\BELLDEC.DOC

1111.64360

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

7-05-01
Date

Express Mail No. EL 846162315 US

DECLARATION OF TERRY KANNOFSKY

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

Terry Kannofsky declares:

1. I am the owner of TK Associates, a Washington D.C. search firm. Among other things, our firm regularly copies documents from patent applications for attorneys.

2. On about June13, 2001, Patrick Burns gave me a power to inspect the above-referenced patent application file in the U.S. Patent and Trademark Office ("PTO"). On June 15, 2001, I personally inspected the file. I did not copy all of the documents in the

1111.64360

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

I hereby certify that this paper is being deposited with the United States Postal Service as EXPRESS mail in an envelope addressed to: Office of Petitions, Box DAC, Assistant Commissioner for Patents, Washington, D.C. 20231, on this date.

Date *Express Mail No.*

DECLARATION OF TERRY KANNOFSKY

Office of Petitions
Box DAC
Assistant Commissioner for Patents
Washington, D.C. 20231

Terry Kannofsky declares:

1. I am the owner of TK Associates, a Washington D.C. search firm. Among other things, our firm regularly copies documents from patent applications for attorneys.

2. On about June13, 2001, Patrick Burns gave me a power to inspect the above-referenced patent application file in the U.S. Patent and Trademark Office ("PTO"). On June 15, 2001, I personally inspected the file. I did not copy all of the documents in the

file, but copied the attached documents (marked as pages TK-1 through TK-39) from the file for this patent application, under the supervision of a PTO employee.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: June 28, 2001

Terry Kannofsky

Terry Kannofsky

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Clas | ISSUE

ATENT NUMBER

U.S. UTILITY Patent Application

O.I.P.E.	PATENT DATE
SCANNED CTH² Q.A.	

CLASS	SUBCLASS	ART UNIT	EXAMINER
310			

TITLE OF INVENTION:

APPLICANT(S):

ISSUING CLASSIFICATION

ORIGINAL		CROSS REFERENCE(S)					
CLASS	SUBCLASS	CLASS	SUBCLASS (ONE SUBCLASS PER BLOCK)				
INTERNATIONAL CLASSIFICATION							
			☐ Continued on Issue Slip Inside File Jacket				

☐ TERMINAL DISCLAIMER	DRAWINGS			CLAIMS ALLOWED	
	Sheets Drwg.	Figs. Drwg.	Print Fig.	Total Claims	Print Claim for O.G.
☐ The term of this patent subsequent to ____________ (date) has been disclaimed.	(Assistant Examiner) (Date)			NOTICE OF ALLOWANCE MAILED	
☐ The term of this patent shall not extend beyond the expiration date of U.S Patent. No. ____________	(Primary Examiner) (Date)			ISSUE FEE: Amount Due	Date Paid
☐ The terminal ____months of this patent have been disclaimed.	(Legal Instruments Examiner) (Date)			ISSUE BATCH NUMBER	

WARNING:
The information disclosed herein may be restricted. Unauthorized disclosure may be prohibited by the United States Code Title 35, Sections 122, 181 and 368. Possession outside the U.S. Patent & Trademark Office is restricted to authorized employees and contractors only.

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(Attached in pocket on right inside flap)

(FACE)

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INITIALS ________

CONTENTS

No.		Date Received (Incl. C. of M.) or Date Mailed
	lication ________ papers. Letr. Incomplete	4-8-01
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PATENT APPLICATION

526 Rec'd PCT/PTO 12 JUN 2000

OIPE JUN 12 2000 PATENT & TRADEMARK OFFICE

Continuation/Divisional Docket No.: **1111.64360**
Parent Docket No.: **N/A**

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: **Sato et al.**
Application No.: **PCT/JP99/05568** Art Unit:
Filed: **October 8, 1999** Examiner:
For: **MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE**

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

NOTIFICATION OF FILING OF CONTINUING OR DIVISIONAL APPLICATION

Notification is hereby being made of the filing of a:

X continuation

_ continuation-in-part

_ divisional

application for this case

X concurrently herewith.

_ on ____________.
Date

Reg No. **41,017**

Tel. No.: (312) 993-0080

SIGNATURE OF ATTORNEY

Jonathan D. Feuchtwang
(type or print name of attorney)

Greer, Burns & Crain, Ltd.

233 S. Wacker Dr. Suite 8660
(address)

Chicago, IL 60606

CERTIFICATION UNDER 37 C.F.R. 1.8(a) and 1.10

I hereby certify that, on the date shown below, this correspondence is being:

X deposited with the United States Postal Service in an envelope addressed to the Assistant Commissioner of Patents, Washington, D.C. 20231

37 C.F.R. 1.8a

_ with sufficient postage as "first class" mail.

37 C.F.R. 1.10

X as "Express Mail" Mailing Label No. **EL409491679US**

June 12, 2000
Date

Signature

Alfredo Zhagui
(type or print name of person certifying)

Notification Form
Rev. February 10, 1998

TK3

09/581468
416 Rec'd PCT/PTO 12 JUN 2000

Docket No.: 1111.64360

PATENT APPLICATION

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Anticipated Classification of this application:
Class: Subclass:

Prior application: **PCT/JP99/05568**

Examiner:

Art Unit:

REQUEST FOR FILING CONTINUING OR DIVISIONAL APPLICATION

BOX PATENT APPLICATION
ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

Sir:

This is a request for filing a

(X) Continuation application,

( ) Divisional application,

under 37 CFR 1.53(b), of pending prior application Serial No. **PCT/JP99/05568** filed on **October 8, 1999**for **MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DRIVE.**

CERTIFICATION UNDER 37 CFR 1.10

I certify that, on the date shown below, these documents are being deposited with the United States Postal Service in an envelope addressed to the Assistant Commissioner of Patents, Washington, D.C. 20231, as "Express Mail Post Office to Addressee," Mailing Label No. **EL409491679US.**

Date June 12, 2000

Signature

TK4

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416 Rec'd PCT/PTO 12 JUN 2000

1. ( ) Enclosed is a copy of the prior application, including the oath or declaration as originally filed. The attached application papers are a true copy of prior application Serial No.: ^^^^ as originally filed on ^^^^ , and no amendments referred to in the oath or declaration as originally filed introduced new matter. This statement is made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

The copy of the papers of the prior application as filed are as follows:

( ) __ pages of specification including claims and abstract
( ) __ sheets(s) of drawing
( ) __ pages of declaration and power of attorney

2. (X) Enclosed is a replacement specification reflecting previously submitted amendments and/or additional formal amendments. No new matter is added by the changes.

The new application includes:

(X) 67 pages of specification including claims and abstract
(X) 25 sheets(s) of drawing
( ) ____ pages of declaration and power of attorney

3. ( ) A statement (Declaration) claiming small entity status was filed in the prior application and small entity status for this application is proper and desired.

4. ( ) Cancel in this application original claims ^^^^ of the prior application before calculating the filing fee. (At least one original independent claim must be retained for filing purposes).

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5. (X) The filing fee is calculated below:

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CLAIMS AS FILED IN THE PRIOR APPLICATION, LESS ANY CLAIMS CANCELED BY AMENDMENT BELOW

For	No. Filed	No. Extra	Rate	Fee
Basic Fee.....				$690.00
Total Claims...	- 20 =		x $18.00 =	$ -0-
Independent Claims....	- 3 =		x $78.00 =	$ -0-
		Total Filing Fee		$
Statement of Status as Small Entity Reducing Filing Fee By Half To				$ -0-

6. ( ) A check in the amount $_______ is enclosed.

7. ( ) The Commissioner is hereby authorized to charge any additional fees which may be required for this application under 37 C.F.R. 1.16-1.17, or credit any overpayment, to Deposit Account No. 07-2069. A duplicate copy of this sheet is enclosed.

8. ( ) A petition and fee for an extension of time has been filed in the pending prior application. A copy of the petition is attached.

9. ( ) Amend the specification by inserting before the first line the sentence: --This is a ( ) continuation, ( ) divisional, ( ) continuation-in-part, of application Serial No. ^^^^ , filed ^^^^ .--

10. (X) Priority of application Serial No. **10-289781** filed on **October 12, 1998** in **Jpaan,** and application Serial No. **10-308989**, filed on **October 29, 1998**, in **Japan** are claimed under 35 U.S.C. 119.

( ) The certified copy(ies) has (have) been filed in prior application Serial No. ^^^^, filed ^^^^ .

11. ( ) The prior application is assigned of record to: ^^^^ . The assignment was recorded on ^^^^ on Reel ^^^^ , Frame ^^^^ .

12. ( ) The inventors of the invention of the parent application, serial number ^^^^ are ^^^^ .

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13. (X) An information disclosure statement is submitted herewith.

14. (X) A preliminary amendment is enclosed herewith.

15. ( ) Please delete the name(s) of ^^^^ who is (are) not a (an) inventor(s) of the subject matter of the ( ) continuing ( ) divisional application.

16. ( ) The power of attorney in the prior application is to:

(X) The power appears in the original papers in the prior application.

( ) Since the power does not appear in the original papers, a copy of the power in the prior application is enclosed.

( ) Associate Power of Attorney is enclosed.

( ) A copy of the Associate Power to ^^^^ is enclosed. The original Associate Power was filed in the parent application.

(X) Address all future communications to:

Patrick G. Burns
Greer, Burns & Crain, Ltd.
Sears Tower - Suite 8660
233 South Wacker Drive
Chicago, Illinois 60606

June 12, 2000

Jonathan D. Feuchtwang
Registration No. **41,017**
Attorney of record

Greer, Burns & Crain, Ltd.
Sears Tower - Suite 8660
233 South Wacker Drive
Chicago, Illinois 60606
(312) 993-0080
Continuation/Divisional Application, 4 pages, 16 paragraphs
Revision November 17, 1998

TX 7

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1111.64360

PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re U.S. Patent Application	)
Applicant: Sato et al.	)
Cont. of: PCT/JP99/05568	)
Filed: October 8, 1999	)
For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE	)
Art Unit:	)

I hereby certify that this paper is being deposited with the United States Postal Service as Express Mail in an envelope addressed to: Asst. Comm. for Patents, Washington, D.C. 20231, on this date.

06/12/00
Date Express Mail Label No.: EL409491679US

PRELIMINARY AMENDMENT

Box Patent Application
Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

Prior to examination of this application, please amend the application as follows:

IN THE CLAIMS:

Please amend claims 5, 6, 10, 11 and 12-17 as follows:

5. (Once Amended) A magnetic head comprising the magnetic sensor according to [any one of claims] claim 1 [to], 4 or 2.

TX9

6. (Once Amended) A magnetic encoder comprising the magnetic sensor according to [any one of claims] claim 1 [to] , 4 or 2.

10. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 9] or 8, wherein

the member of high permeability is a shield layer formed, spaced from the ferromagnetic tunnel junction element.

11. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 10] or 8, wherein

the thickness of the barrier layer near the edge of the fixed layer is larger than a thickness of the barrier layer near a central part of the fixed layer.

12. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 11] or 8, wherein

the free layer is formed wider in a region spaced from the signal detection surface.

13. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 12] or 8, wherein

the fixed layer is not exposed to the signal detection surface.

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14. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 13] or 8, wherein

the member of high permeability is grounded.

15. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 14] or 8, wherein

the free layer in a region which is not opposed to the fixed layer is bent away from the fixed layer.

16. (Once Amended) A magnetic head according to [any one of claims] claim 7 [to 15] or 8, wherein

the ferromagnetic tunnel junction element further includes another fixed layer which is opposed to the free layer through another barrier layer formed on the other surface of the free layer, a magnetic direction of said another fixed layer being fixed by another antiferromagnetic layer which is adjacent thereto.

17. (Once Amended) A hard disk device comprising the magnetic head according to [any one of claim 5 and claims] claim 7 [to 16] or 8.

TK/11

REMARKS

Applicants respectfully request that these claims be considered with the examination of the remaining claims.

Respectfully submitted,

GREER, BURNS & CRAIN, LTD.

By [signature]
Jonathan D. Feuchtwang
Registration No. 41,017

June 12, 2000

Suite 8660 - Sears Tower
233 S. Wacker Drive
Chicago, Illinois 60606-6501
Telephone: (312) 993-0080
Facsimile: (312) 993-0633

TK12

09/581468

FIG. 1A

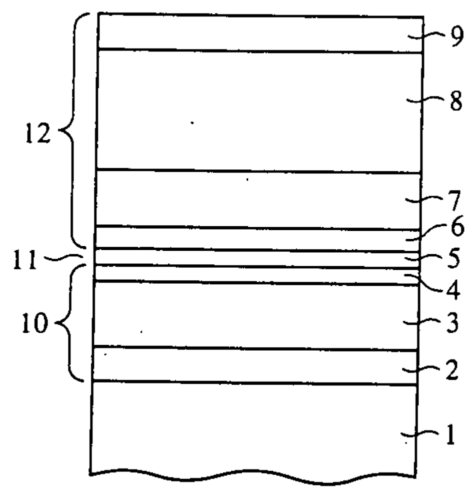
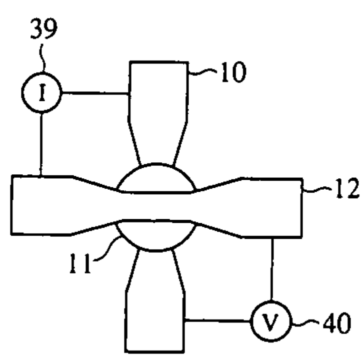


FIG. 1B



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09/581468

FIG. 2

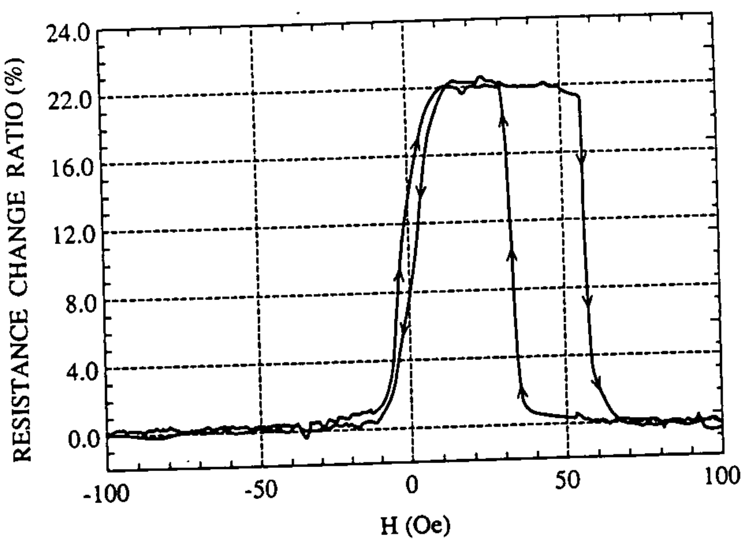

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FIG. 3

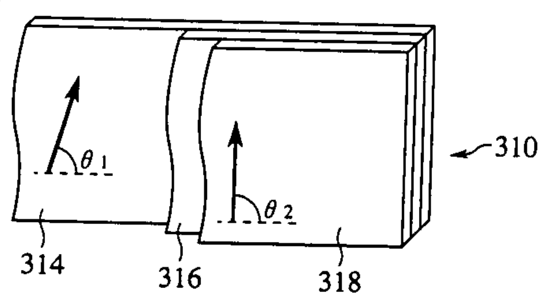

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FIG. 4

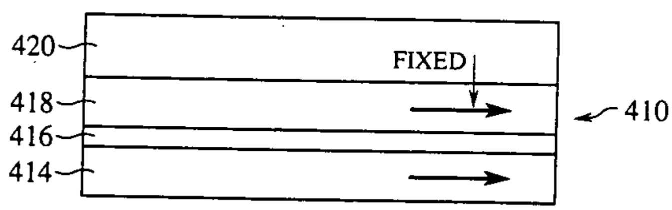

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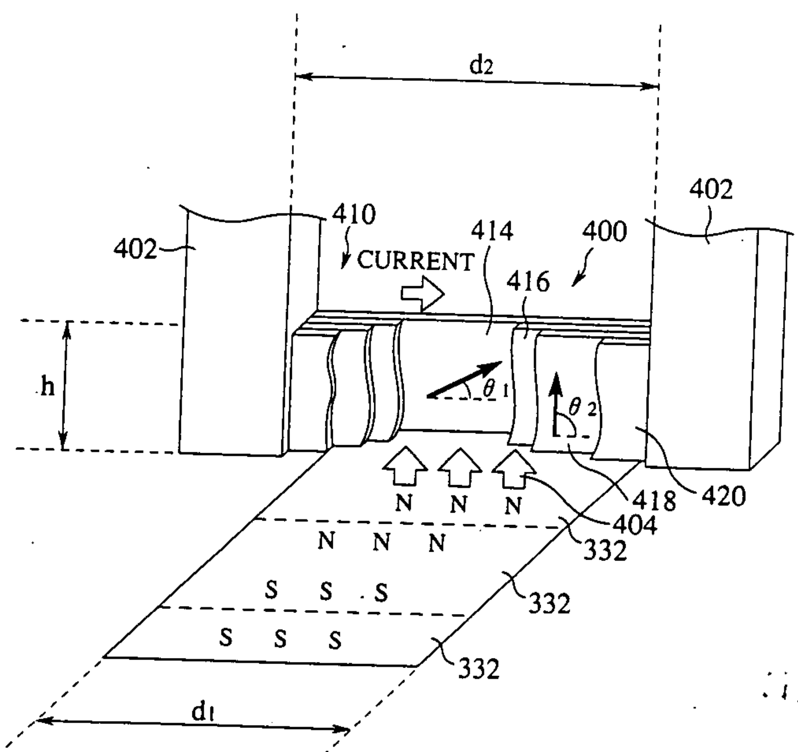
FIG. 5



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09/581468

FIG. 6

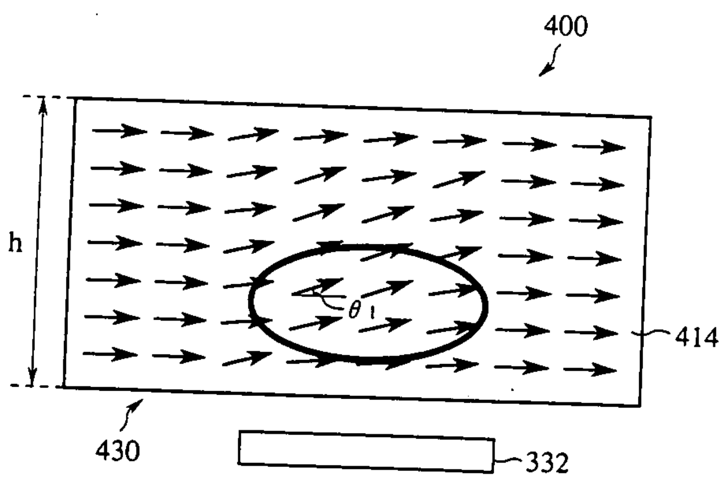

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FIG. 7A

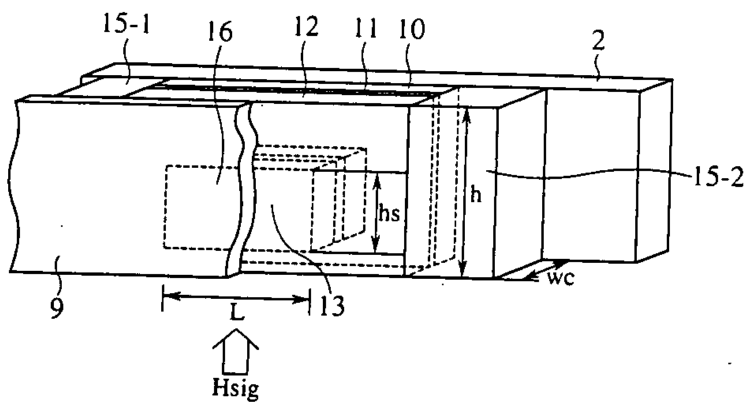

FIG. 7B

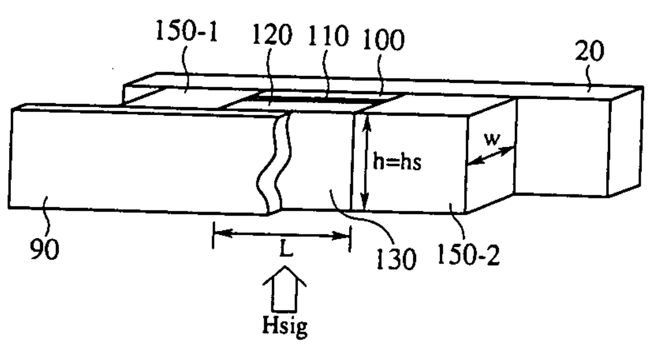

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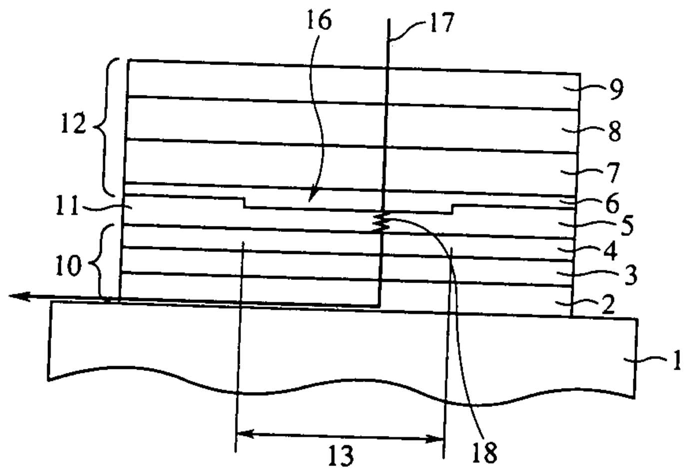
FIG. 8



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09/581468

FIG. 9A

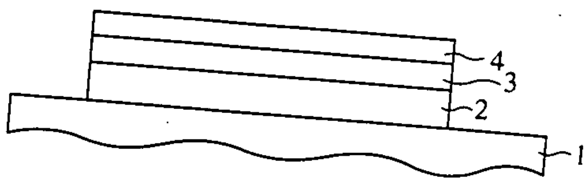


FIG. 9B

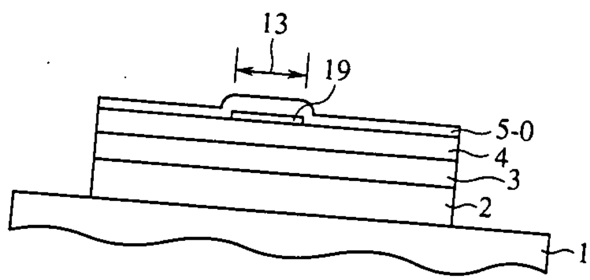


FIG. 9C

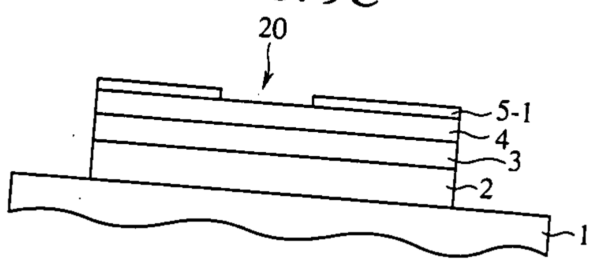
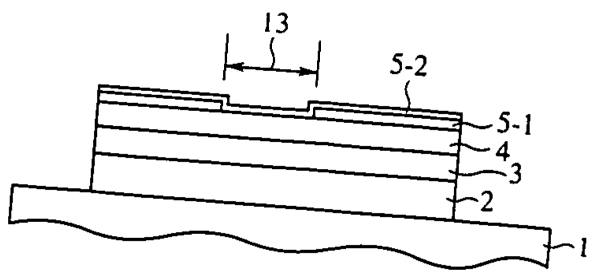


FIG. 9D



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09/581468

FIG. 10A

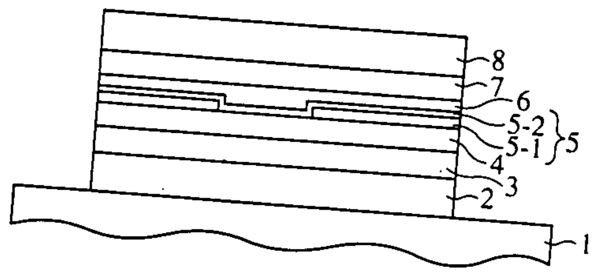

FIG. 10B

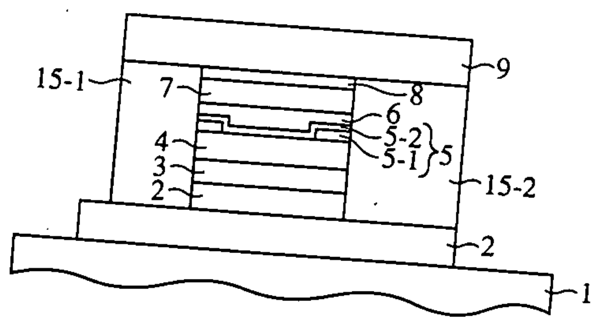

FIG. 10C

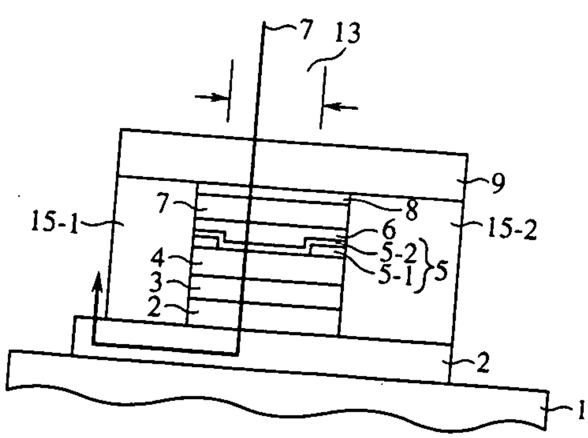

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FIG. 11A

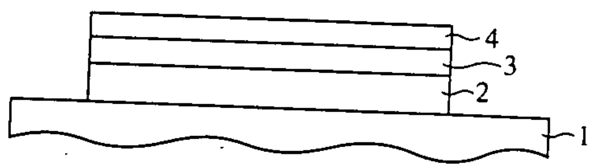

FIG. 11B

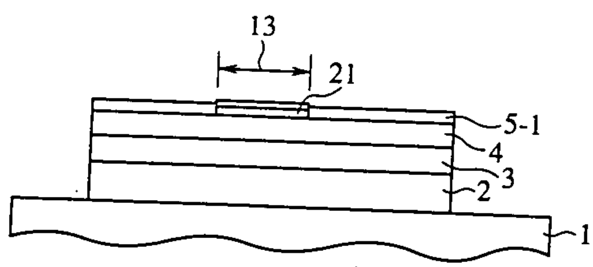

FIG. 11C

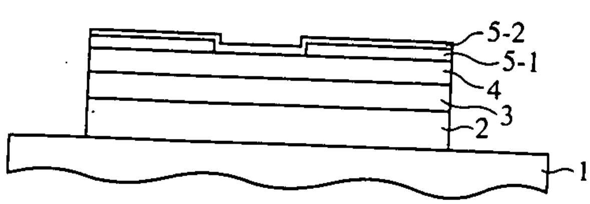

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FIG. 12A

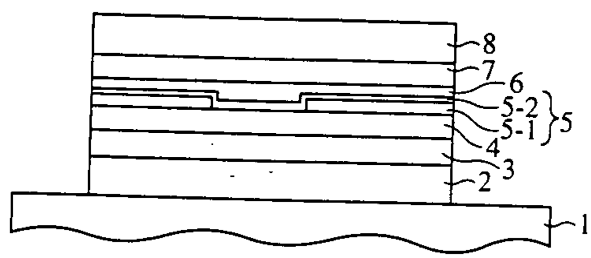

FIG. 12B

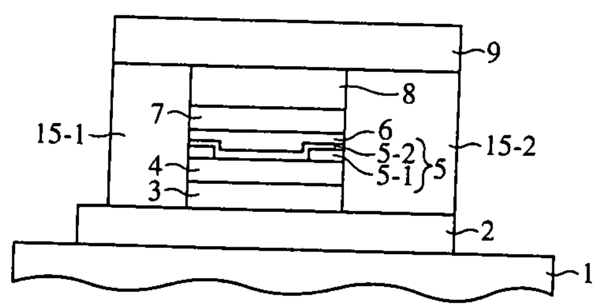

FIG. 12C

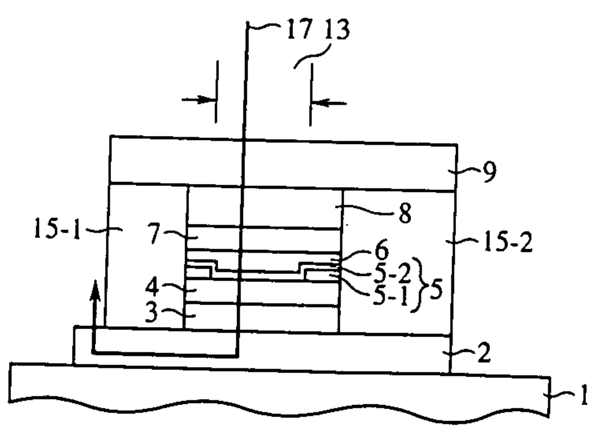

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FIG. 13A

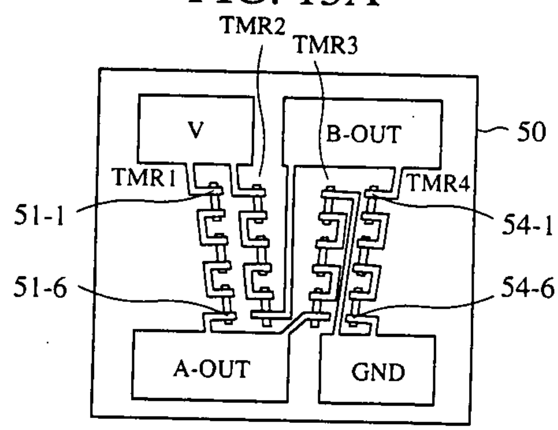

FIG. 13B

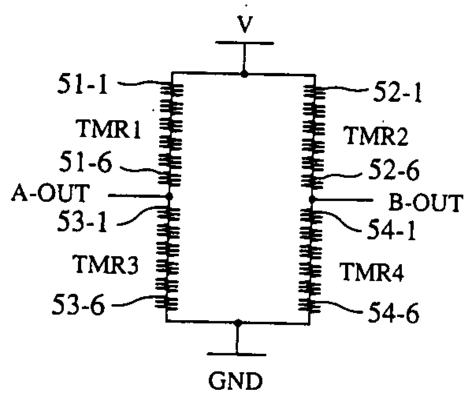

FIG. 13C

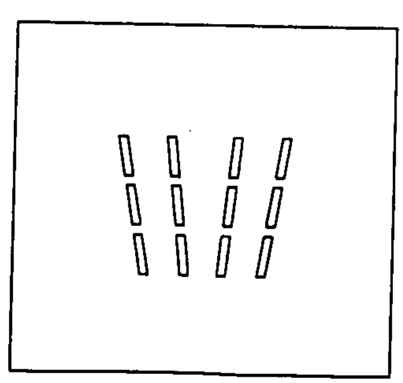

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FIG. 14A

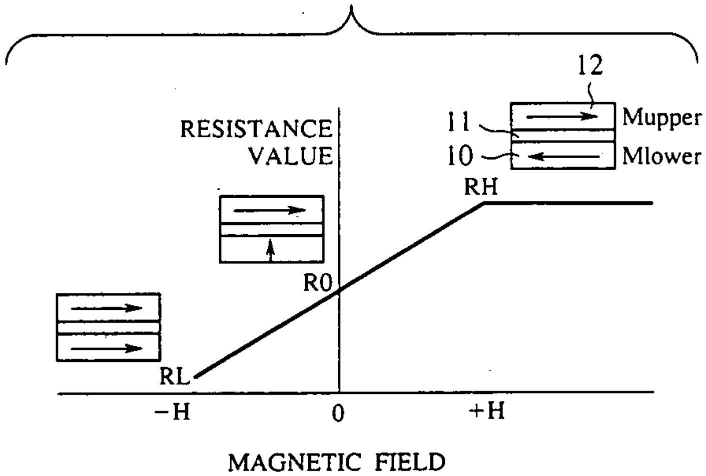

FIG. 14B

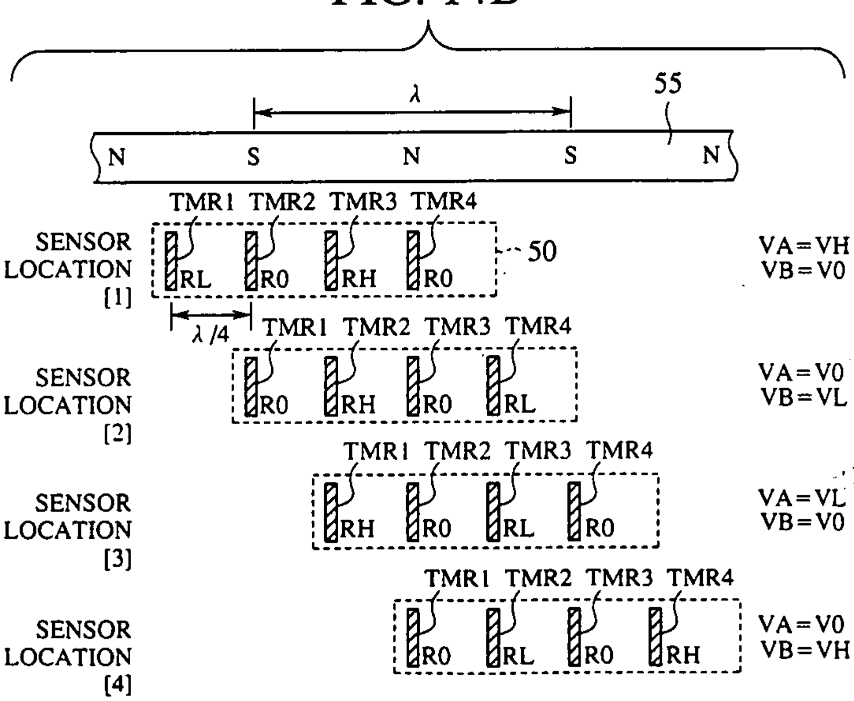

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FIG. 15A

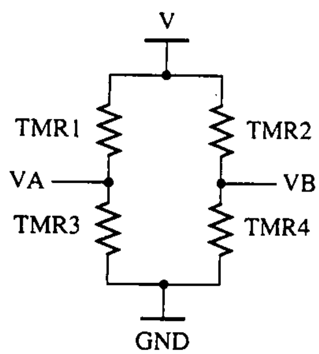

FIG. 15B

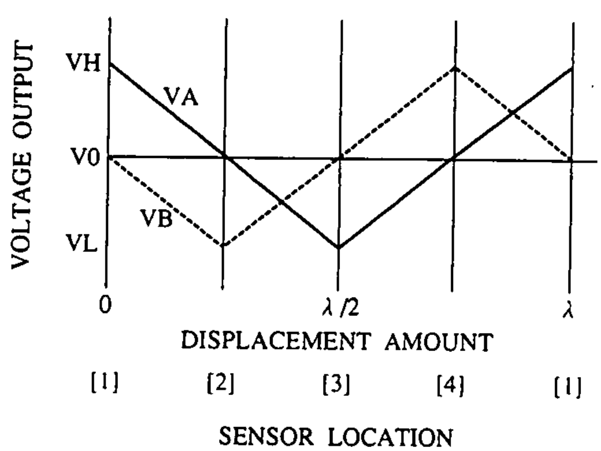

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FIG. 16A

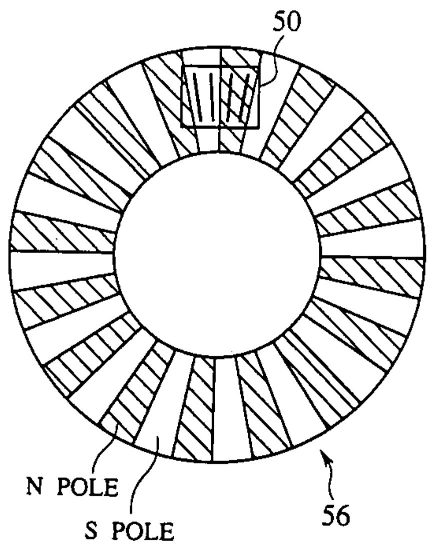

FIG. 16B

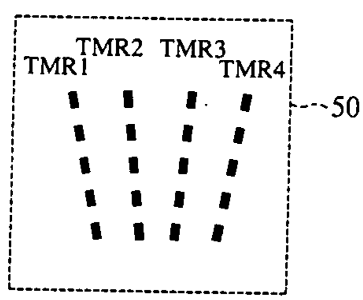

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FIG. 17A

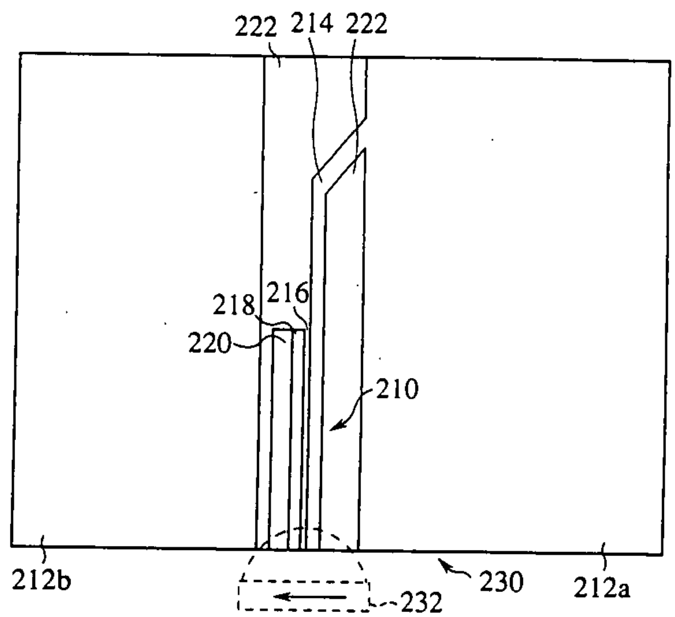

FIG. 17B

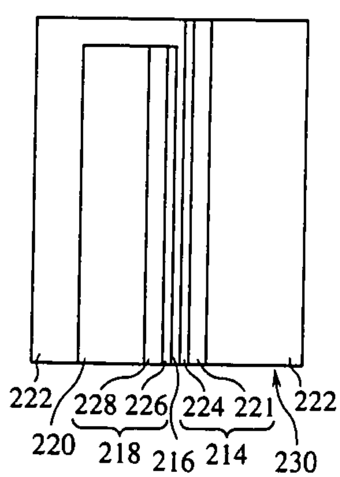

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FIG. 18

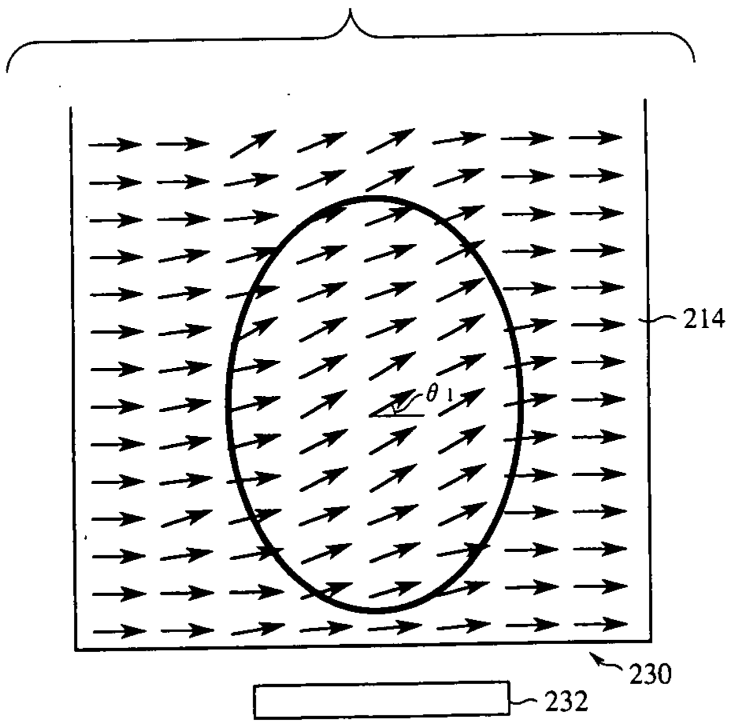

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FIG. 19A

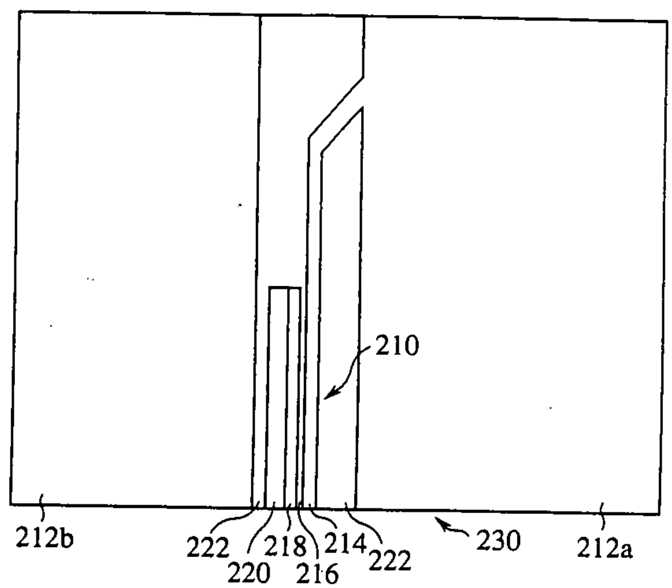

FIG. 19B

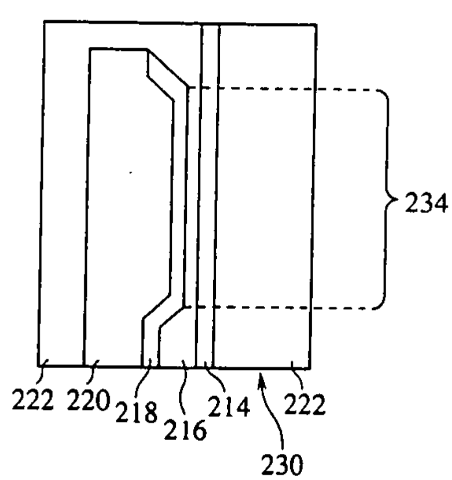

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FIG. 20

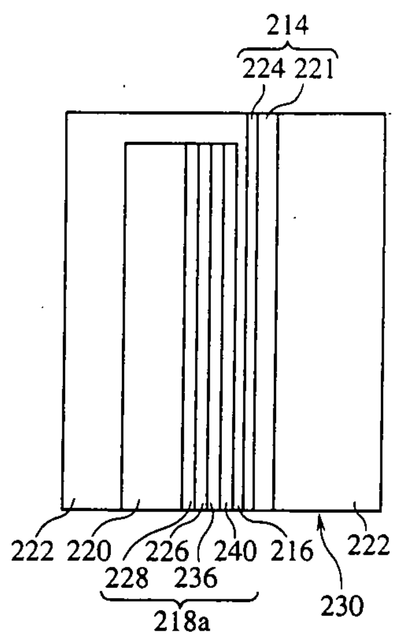

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FIG. 21A

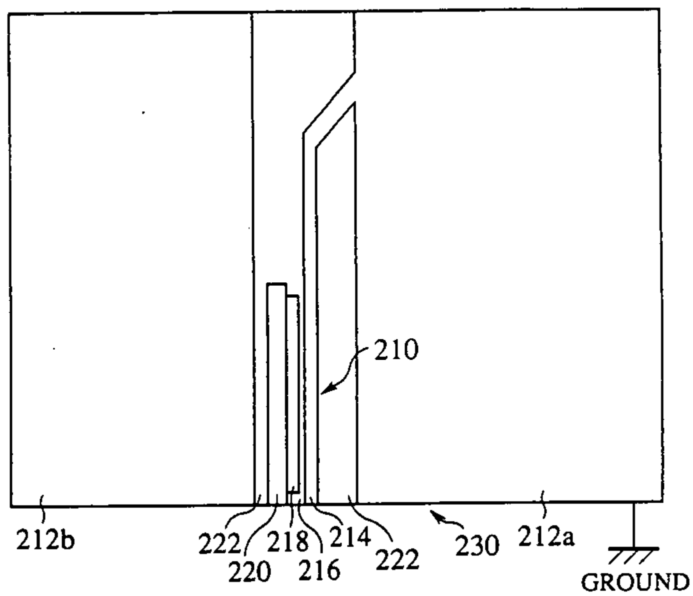

FIG. 21B

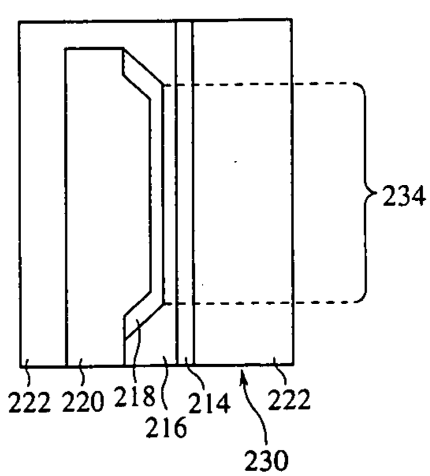

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FIG. 22

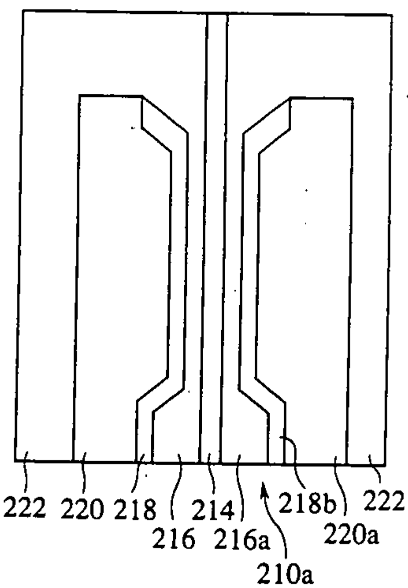

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FIG. 23

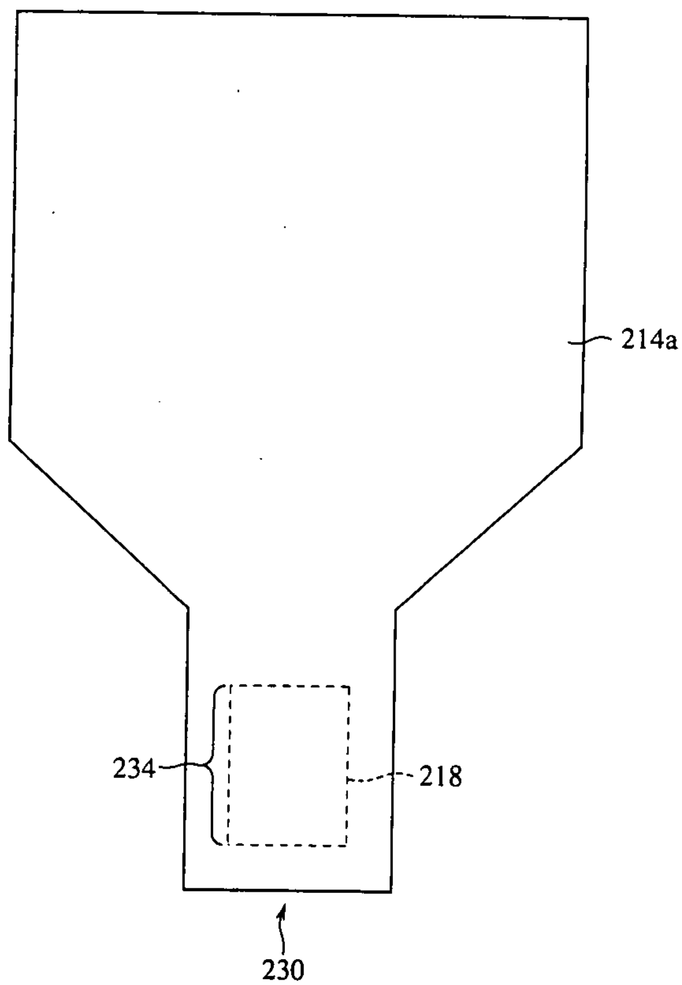

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FIG. 24

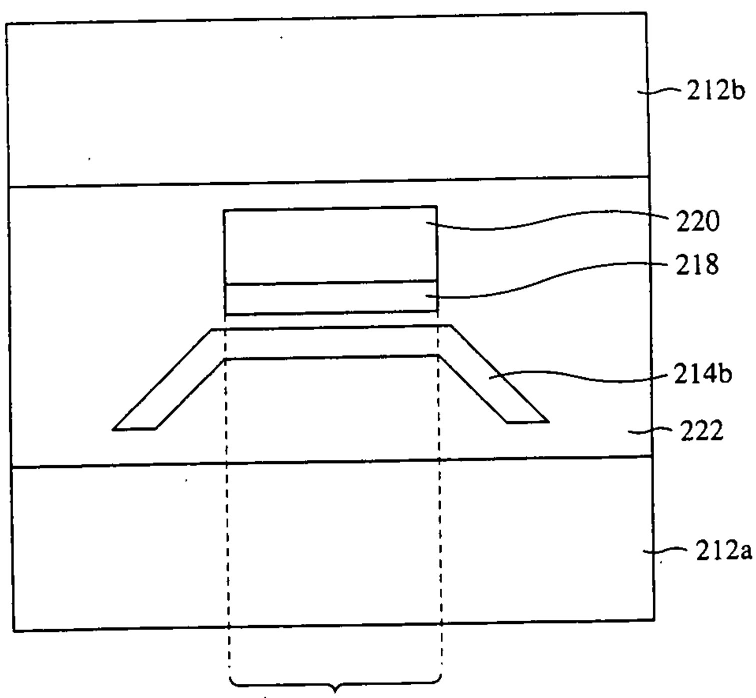

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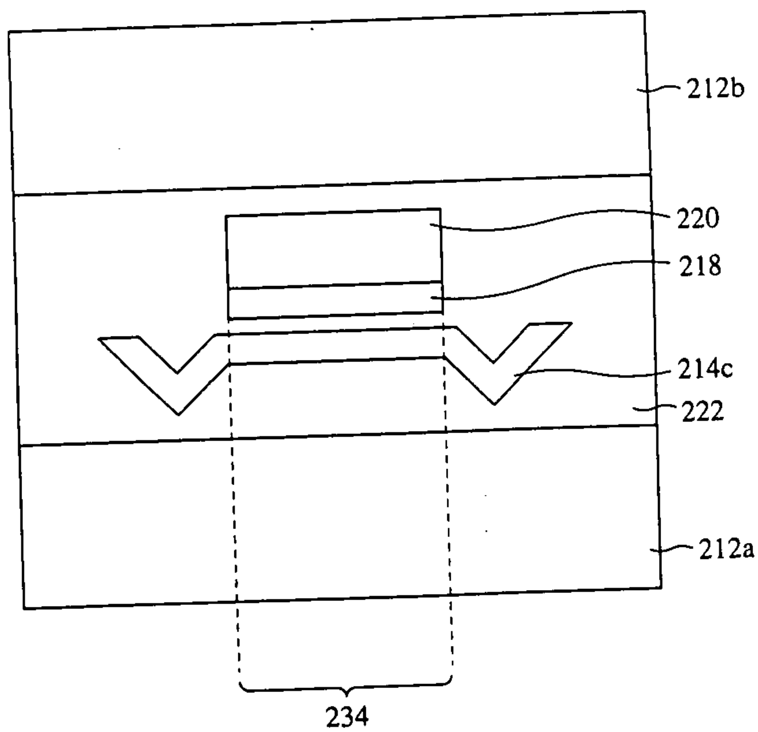
FIG. 25



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MAGNETIC SENSOR, MAGNETIC HEAD...
Sato et al.
Cont. of PCT/JP99/05568
Filed: 10-8-99
Greer, Burns & Crain, Ltd. (Patrick Burns)
File No. 1111.64360
(312) 993-0080
Sheet 25 of 25

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PATENT

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant: Sato et al.

Serial No.: 09/581,468

Filed: June 12, 2000

For: MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

Art Unit:

Examiner:

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DECLARATION OF JONATHAN D. FEUCHTWANG

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Jonathan D. Feuchtwang declares:

1. I am licensed to practice law in the State of Illinois, and I am registered to practice in the U.S. Patent and Trademark Office ("PTO").

2. In June 2000, I was an attorney employed by Greer, Burns & Crain, Ltd. ("GBC"). Among other things, I was responsible for filing new patent applications as requested.

3. My practice when filing new patent applications at GBC was to personally review all of the application papers when they were ready to be filed, and to personally place the application papers in a properly addressed envelope, seal the envelope and deliver the sealed envelope to the person who signed the certificate of mailing.

4. In the course of reviewing the papers, I personally counted each page of the specification and each page of drawings, among other things. I followed this practice in every application I filed at GBC.

5. On June 12, 2000, I filed a continuation application of Serial No. PCT/JP99/05568 under 35 U.S.C. § 111(a). Because I followed the practices described above every time I filed an application, 67 pages of specification, claims and an abstract, as well as 25 sheets of formal drawings, and other papers identified in the transmittal letter and postcard receipt, were enclosed in the envelope sent to the PTO.

6. A photocopy of the express mail receipt for this application is attached as Exhibit A. Among other things, the receipt indicates that a package weighing 2 lbs., 6.4 oz. was accepted by the U.S. Postal Service on June 12, 2000.

7. A photocopy of postcard receipt for this application is attached as Exhibit B. This postcard was included with the application I filed on June 12, 2000, and shows receipt by the U.S. Patent and Trademark Office of 67 pages of specification, claims and an abstract, and 25 sheets of formal drawings, among other things.

8. A true and correct copy of the 67 pages of specification, claims and an abstract, and the 25 sheets of formal drawings filed in the U.S. Patent and Trademark Office on June 12, 2000, is attached as Exhibit C.

I declare under penalty of perjury that the foregoing is true and correct.

Executed: 6/25/01

Jonathan D. Feuchtwang
Registration No. 41,017

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In re Cont. Patent Application of
Sato et al.
For: MAGNETIC SENSOR, MAGNETIC HEAD . . .
Cont.of PCT/JP99/05568
Filed: 10-8-99
Asst. Commissioner for Patents

PATENT
1111.64360
JDF:kmw
June 12, 2000

09/581468

Notification of filing continuing or divisional application; Rquest for filing continuing or divisional application; Preliminary amendment; Patent application including 67 pages of spec. and claims and an abstract; Unexecuted power of attorney; 25 sheets of formal drawings; IDS, PTO Form 1449 w/cited references; and Certificate of Express Mail No. EL409491679US.

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DESCRIPTION

MAGNETIC SENSOR, MAGNETIC HEAD, MAGNETIC ENCODER AND HARD DISK DEVICE

[CROSS REFERENCE TO RELATED APPLICATION]

This application is a Continuation of PCT application No. PCT/JP99/05568, which was filed on October 8, 1999, and which designated the United States.

[TECHNICAL FIELD]

The present invention relates to a magnetic sensor, a magnetic head, a magnetic encoder and a hard disk device, more specifically, a magnetic sensor, a magnetic head, a magnetic encoder and a hard disk device which utilize a ferromagnetic tunnel junction.

[BACKGROUND ART]

Some electronic devices utilize tunnel phenomenon. The tunnel phenomenon generally means a phenomenon that particles, e.g., electrons, etc., having lower kinetic energy than a potential barrier can pass the potential barrier to transit. The tunnel phenomenon is a phenomenon which cannot be explained by classical mechanics, but is characteristics of quantum mechanics and can be explained by quantum mechanics. A wave function of a particle

propagates inside the potential barrier toward outside the potential barrier, attenuating, and unless an amplitude of the wave function is zero outside the potential barrier, the wave function propagates as a progressive wave, and can exit the potential barrier.

As examples of the tunnel phenomenon are known the phenomenon that α-particle is emitted from an atomic nucleus by α-decay, the phenomenon that electrons are emitted from the surface of a metal when a high voltage is applied to the metal (field emission), the phenomenon that when a high reverse bias is applied to a pn junction of a semiconductor, electrons punch through a depletion layer, and other phenomena. The tunnel phenomenon is practically a very important quantum mechanic effect.

A typical phenomenon as the tunnel phenomenon used in electronic devices is that when a voltage is applied to the metals on both sides of a "metal/insulator/metal" junction, a little current flows when the insulation is sufficiently thin. This phenomenon is one that takes place because an electron has a low probability of passing through an insulator, which usually does not conduct current, owing to the quantum mechanic effect when the insulator has a thickness of some angstroms (Å) to tens Å and is as thin as preferably some Å to ten-order Å. The current is called "tunnel current", and a junction of such structure is called a "tunnel junction".

In order to realize a very thin insulation layer for realizing the tunnel junction, usually an oxide film of a metal layer is used as an insulator barrier. For example, such insulator barrier is formed by oxidizing a surface layer of aluminum by suitable oxidation, such as natural oxidation, plasma oxidation, thermal oxidation or others. A film thickness of an oxide film can be controlled by adjusting oxidation conditions in accordance with used oxidation, and can have a required thickness of some angstroms (Å) to tens Å. The thus-formed aluminum oxide is a very thin insulator and can function as a barrier layer of a tunnel junction.

When a voltage is applied between the metals of the tunnel junction of the above-described "metal / oxide film / metal", which are on both sides thereof, the current corresponding to the applied voltage characteristically exhibits non-linearity, which is different from linearity exhibited by the usual resistor. Electronic devices having such tunnel junction are used as non-linear devices.

Then, the structure "ferromagnetic metal / oxide film / ferromagnetic metal", which has the metals of the "metal / oxide film / metal" on both sides replaced by the ferromagnetic metals is called "ferromagnetic tunnel junction". It is known that in the ferromagnetic tunnel junction a tunnel probability (tunnel resistance) depends on a magnetized state of the magnetic layers on both sides.

In other words, it is possible to control the tunnel resistance by changing a magnetized state of the magnetic layers on both sides by a magnetic field. When a relative angle between magnetic directions of both magnetic layers is represented by θ, a tunnel resistance R is expressed by

$$R = R_s + 0.5 \times \Delta R \ (1 - \cos\theta) \quad \ldots\ldots\ldots \ (1)$$

R_s represents a tunnel resistance at the time that a saturated magnetic field is applied. Two magnetic directions on both sides are oriented in directions of the magnetic field application. ΔR represents a change of the tunnel resistance.

What Formula (1) means is that when the two magnetic layers are magnetized in the same direction in a saturated magnetic filed, a relative angle $\theta=0°$ ($\cos\theta=1$), and a tunnel resistance $R=R_s$. In contrast to this, when the two magnetic layers are magnetized in direction opposite to each other in a saturated magnetic field, a relative angle in the magnetic directions $\theta=180°$ ($\cos\theta=-1$), and a tunnel resistance $R=R_s+\Delta R$. In the absence of a magnetic field, as will be described later, one of the two magnetic layers has a magnetic direction fixed as the magnetic layer on the fixed side, and the other magnetic layer has a magnetic field direction weakly controlled in a domain as the magnetic layer on the free side so that the magnetic filed direction is orthogonal to a magnetic direction of the fixed side-magnetic layer. At this time, a relative angle

between the magnetic direction of the two magnetic layers is $\theta=90°$ ($\cos\theta=0$), and a tunnel resistance $R=R_s+0.5\times\Delta R$.

That is, when magnetic directions of both magnetic layers agree with each other ($\theta=0°$), a tunnel resistance $R=R_s$, which is minimum. When magnetic directions of both magnetic layers are opposite to each other ($\theta=180°$), a tunnel resistance $R_0=R_s+\Delta R$, which is maximum. Accordingly, magnetic directions of both magnetic layers are set in the absence of a magnetic field to be $\theta=90°$, whereby a resistance value changes linearly, centering on a resistance value given when $\theta=90°$, and linear outputs can be obtained.

Such phenomenon is attributable to that electrons in the ferromagnetic bodies are polarized. Usually electrons in a substance are up electrons, whose spin state is upward, and down electrons, whose spin state is downward. The non-magnetic metal has equal numbers of up electrons and down electrons, and does not exhibit magnetism as a whole non-magnetic metal. However, the magnetic metal has a number of up electrons (N_{up}) and a number of down electrons (N_{down}) which are different from each other, and exhibits as a whole magnetic metal magnetism (i.e., up magnetism or down magnetism) of the electrons whose number is larger.

It is known that electrons tunnel one of the magnetic layers on both sides to the other magnetic layer through

the thin oxide film, these electrons tunnel with spin states of the respective electrons retained. Accordingly, when an electron state of the tunneled magnetic layer has voids, the tunneling is possible, but the tunneling is impossible when the electron state of the tunneled magnetic layer has no void.

As expressed below, a tunnel resistance change ratio ($\Delta R/R_s$) is expressed by using a product of a polarizability (also called deflected magnetic susceptibility) of a magnetic layer (to tunnel) as an electron source and a polarizability of a magnetic layer (to be tunneled).

$$\Delta R / R_s = 2 \times P_1 \times P_2 / (1 - P_1 \times P_2) \quad \ldots\ldots\ldots (2)$$

where P_1 represents a polarizability of one of the magnetic layers, and P_2 represents a polarizability of the other of the magnetic layers. A polarizability P of the magnetic layer is expressed as follows.

$$P = 2 \times (N_{up} - N_{down}) / (N_{up} + N_{down}) \quad \ldots\ldots\ldots (3)$$

where N_{up} represents a number of up electron in the magnetic layer, and N_{down} represents a number of down electrons in the magnetic layer.

A polarizability P of a magnetic layer depends on a kind of a ferromagnetic layer metal. However the magnetic layer often has a polarizability of approximately 50% depending on a kind, and in this case a tunnel resistance change ratio ($\Delta R/R_s$) of tens percent can be expected.

As the conventionally known magnetoresistance (MR)

effect, a resistance change ratio is about 0.6% for anisotropic magnetoresistance (AMR) effect, and for giant magnetoresistance (GMR) effect, a resistance change ratio is some percentage to ten-order percent. The tunnel resistance change ratio is remarkably higher in comparison with the changes of AMR and GMR, and can be expected to be applied to magnetic heads, magnetic sensors, etc.

As a typical application of GMR to a magnetic head, the spin valve structure is known. The applicant of the present application has already proposed a TMR (tunnel-MR) head having the above-described ferromagnetic tunnel junction applied to the spin valve structure.

The spin valve structure uses a structure in which a magnetic metal layer is disposed between two magnetic layers, and an antiferromagnetic layer covers the upper surface of one of one of the magnetic layers so as to fix a magnetic direction of said one of the magnetic layers. As a ferromagnetic tunnel junction, a thin oxide film is disposed between two ferromagnetic layers as described above.

FIG. 1A is a sectional view explaining the ferromagnetic tunnel structure. The spin valve structure having the ferromagnetic tunnel junction typically comprises, as exemplified in FIG. 1A, a lower electrode 2 formed on a silicon substrate 1, a free-side magnetic layer 3 formed on the lower electrode, a first magnetical metal

layer 4 formed on the free-side magnetic layer, an insulation layer 5 formed on the first magnetic metal layer, a second magnetic metal layer 6 formed on the insulation layer, a fixed-side magnetic layer 7 formed on the second magnetic metal layer, an antiferromagnetic layer 8 formed on the fixed-side magnetic layer, and an upper electrode 9 formed on the antiferromagnetic layer 8.

The lower electrode 2, the free-side magnetic layer 3 and the first magnetic metal layer 4 form a lower layer 10, and the second magnetic metal layer 6, the fixed-side magnetic layer 7, the antiferromagnetic layer 8 and the upper electrode 9 form an upper layer 12. A barrier layer 11 of an insulation layer 5 is formed between the lower layer 10 and the upper layer 12, isolating both from each other.

Respective members of the spin valve structure are as exemplified below. The substrate 1 is formed of silicon. The lower electrode 2 and the upper electrode 9 are respectively formed of a Ta (tantalum) film and has an about 50 nm-thickness. The free-side magnetic layer 3 and the fixed-side magnetic layer 7 are respectively formed of an NiFe film and has an about 17 nm-thickness. The first and the second magnetic metal layers 4, 6 are formed respectively of a Co (cobalt) film and has an about 3.3 nm-thickness. The insulation layer 5 is formed of an Al-Al_2O_3 film and has an about 1.3 nm-thickness. The

antiferromagnetic layer 8 is formed of an FeMn film and has an about 45 nm-thickness.

The former NiFe film is one of two ferromagnetic layers and is called the free-side magnetic layer (free layer) 3 because its magnetic direction is not fixed. An Al-AlO film sandwiched between both Co films 4, 6 provides the barrier layer 11 formed of a thin aluminum oxide film, which forms the ferromagnetic tunnel junction. The second NiFe film is the other ferromagnetic layer and is called the fixed-side magnetic layer (pinned layer) 7 because a magnetic direction is fixed. The first magnetic metal layer 4 makes the same function as the free-side magnetic layer 3, and the second magnetic metal layer 6 makes the same function as the fixed-side magnetic layer 7. The FeMn film exchange-couples with the fixed-side magnetic layer 7 to fix a magnetic direction of the fixed-side magnetic layer and is called an antiferromagnetic layer (pinning layer) 8.

In the structure of such "free-side magnetic layer / insulation layer / fixed-side magnetic layer / antiferromagnetic layer", when an external magnetic field (e.g., a signal magnetic field from a recording medium) is applied, magnetic directions of the free-side magnetic layer 3 and the first magnetic metal layer 4 alone are rotated. As a result, mainly a relative angle θ between a magnetic direction of the first magnetic metal layer 4 and

that of the second magnetic metal layer 6 is changed, and a resistance change of the ferromagnetic tunnel junction is exhibited. That is, as shown by Formula (1), the tunnel resistance of the TMR (tunnel MR) changes depending on a magnetic field.

FIG. 1B is a schematic diagram explaining the measurement of resistance changes of a magnetic sensor using the ferromagnetic tunnel structure shown in FIG. 1A. A current source 39 is connected between the upper layer 12 and the lower layer 10, and certain current is charged. A voltage detector 40 is also connected between the upper layer 12 and the lower layer 10, and voltage changes between both layers are detected. When an external magnetic field (e.g., a signal magnetic field) is applied, a tunnel resistance of the ferromagnetic tunnel structure shown in FIG. 1A changes, and the tunnel resistance change is detected by the voltage detector 40 as a voltage change.

FIG. 2 shows a magnetoresistance effect curve of the tunnel structure using such spin valve structure. Based on FIG. 2, as an external magnetic field sequentially changes from -50 oersted (Oe) to -10 (Oe), to 0 (Oe), to +10 (Oe) and to +50 (Oe), reversible resistance change ratios of about 0.0% to about 0.0%, to about 10.0%, to about 20.0% and about 20.0% are exhibited. It has been found that the tunnel structure having the spin valve structure as shown in FIG. 2 exhibits substantially linear resistance change

ratios of about 0% to 20% in an external magnetic field range of -10 (Oe) to +10 (Oe). Resistance change ratios of about 0% to 20% are exhibited in an external magnetic field range of -30 (Oe) to +30 (Oe). The resistance change ratios are converted to data of the logic [0], [1], whereby the resistance change ratios can be used in digital logic circuits.

However, in applying the tunnel structure having the spin valve structure to the magnetic sensor of a magnetic head, magnetic encoder or others, in a case that a device height h is too small, rotation of magnetic directions is often difficult near the edge of the device, which leads to a disadvantage that a sensitivity of the magnetic sensor is lowered.

In a case that practical device dimensions are in the order of some microns × some microns, when a device height h is decreased, static magnetic coupling of the fixed-side magnetic layer to the free-side magnetic layer becomes relatively stronger, and a magnetic direction of the free-side magnetic layer tends to be anti-parallel with a magnetic direction of the fixed-side magnetic layer, which makes it difficult for the magnetic direction to rotate in a direction of easy rotation. As a result, a sensitivity of the magnetoresistance effect device is lowered.

On the other hand, hard disk devices are prevalently used in electronic apparatuses because of their high speed

of reading and writing data and large storage capacities.

The recent increase of storage capacities of the hard disk devices is remarkable, but further storage capacity increase is required.

To realize larger storage capacities of the hard disk devices it is an essential requirement that magnetic storage medium, i.e., magnetic disk mediums have higher recording densities. Recording density increase makes a recording bit of the magnetic recording medium smaller. It is necessary that the magnetic head is accordingly micronized, and the detection sensitivity is higher.

Recently, as a magnetic head of high detection sensitivity GMR (Giant Magneto-Resistance effect) head is proposed.

The GMR head is a magnetic head using the phenomenon that when an external magnetic field is applied to a layer film having a magnetic layer / a non-magnetic layer / a magnetic layer structure, an electric resistance of the layer film changes due to a difference between magnetized angles of the two magnetic layers, i.e., the GMR effect.

The GMR effect will be explained with reference to FIG. 3. FIG. 3 is a conceptual view of the GMR effect.

As shown in FIG. 3, the layer film 310 producing the GMR effect has the non-magnetic layer 316 sandwiched between the magnetic layer 314 and the magnetic layer 318. θ_1 indicates a magnetized angle of the magnetic layer 314.

θ_2 indicates a magnetized angle of the magnetic layer 318. The magnetic layer 314 is magnetized at a magnetization vector M_1, and the magnetic layer 318 is magnetized at a magnetization vector M_2.

As shown in FIG. 3, a magnetic field is applied to the layer film 310 from the outside, a magnetized angle of the magnetic layer 314 becomes, e.g., θ_1 and a magnetized angle of the magnetic layer 318 becomes, e.g., θ_2.

When a difference between a magnetized angle θ_1 and a magnetized angle θ_2 is θ,

$$\theta = \theta_2 - \theta_1$$

When an electric resistance at the time that no magnetic field is applied from the outside is R_s, an electric resistance R at the time that a magnetic field is applied from the outside is expressed by

$$R = R_s + 0.5 \times \Delta R (1 - \cos\Delta\theta)$$

where ΔR is a constant which is different for materials of the layer film 310.

A value represented by

$$\Delta R / R_s \times 100 (\%)$$

is called an MR ratio. When the magnetic layer 314 is formed of, e.g., Co layer, the non-magnetic layer 316 is formed of, e.g., Cu layer, and the magnetic layer 318 is formed of, e.g., Co layer, the MR ratio is about 5 - 10%.

In using the layer film producing such GMR effect to a magnetic head, generally a structure called a spin valve

is used. The spin valve structure is published in the specification of Japanese Patent Laid-Open Publication No. 358310/1992.

The spin valve structure will be explained with reference to FIG. 4. FIG. 4 is a sectional view showing a layer film of the spin valve structure.

As shown in FIG. 4, the layer film 410 of the spin valve structure is formed of a magnetic layer 414, a non-magnetic layer 416 and a magnetic layer 418, and an antiferromagnetic layer 420.

In the layer film of the three-layer structure simply formed of the magnetic layer 414, the non-magnetic layer 416 and the magnetic layer 418, a magnetic direction of the magnetic layer 414 and that of the magnetic layer 418 substantially agree with each other due to an external magnetic field, and a magnetized angle difference between a magnetized angle of the magnetic layer 414 and that of the magnetic layer 418 is very small.

Then, the layer film 410 of the spin valve structure has the antiferromagnetic layer 420 formed on the magnetic layer 418. The antiferromagnetic layer 420 fixes only a magnetic direction of a magnetic direction of the magnetic layer 418 contacting the antiferromagnetic layer 420. A magnetic direction of the magnetic layer 414 alone freely rotate corresponding to an external magnetic field. The magnetic layer 418, whose magnetic direction is fixed, is

called a fixed layer, and the magnetic layer 414, whose magnetic direction freely rotates, is called a free layer.

A magnetic direction of the magnetic layer 418 is fixed constant, and a magnetic direction of the magnetic layer 414 is freely rotated by an external magnetic field, whereby an electric resistance R of the layer film 410 is changed corresponding to an external magnetic field.

Next, an operational principle of the magnetic head using the spin valve structure will be explained with reference to FIG. 5. FIG. 5 is a perspective view of the magnetic head using the spin valve structure, which shows the operational principle thereof.

As shown in FIG. 5, the layer film 410 of the spin valve structure formed of the free layer 414, the non-magnetic layer 416, the field layer 418 and the antiferromagnetic layer 420 is used as a core 400, and terminals 402 are formed on both ends of the core 400.

A magnetized angle θ_1 of the free layer 414 is freely changed corresponding to a magnetic field 404 from a recording bit 332 of a magnetic storage medium, but an magnetized angle θ_2 of the fixed layer 418 remains fixed. Thus, a difference between a magnetized angle θ_1 of the free layer 414 and the magnetized angle θ_2 of the fixed layer 48 can be made large, and electric resistance changes of the core 400 at the time that the recording bit 332 comes nearer can be larger.

However, as a magnetic record medium has higher recording density, a track width d_1 is accordingly decreased. A core width d_2 of the magnetic head must be decreased to correspond to a decreased track width d_1. To this end, simply decreasing a core width d_2 makes electric resistance changes of the core 400 smaller, which leads to lower detection sensitivity. Accordingly, when a core width d_2 is decreased, a height h of the core 400 as well must be decreased.

However, when a height h of the core 400 is decreased, as shown in FIG. 6 a magnetic direction on the side of a signal detection plane 430 of the core 400 is not easily changed near the upper part of the core 400 under the influence of the demagnetizing field, and electric resistance changes of the core 400 are small. FIG. 6 indicates magnetic directions of the free layer 414 by the arrows when a height of the core 400 is, e.g., 5 μm. The region enclosed by the ellipse is a region where a magnetized angle θ_1 becomes above a certain angle. As shown in FIG. 6, the region where a magnetized angle θ_1 becomes above a certain angle, and additionally the magnetized angle θ_1 is small.

Thus, the proposed magnetic head of the spin valve structure has the detection sensitivity much lowered when smaller-sized, and has found it difficult to adapt itself to higher density of the magnetic storage mediums.

In consideration of the above-described problems, a first object of the present invention is to provide a novel magnetic sensor, a magnetic head, and an encoder.

A second object of the present invention is to provide a magnetic sensor, a magnetic head and an encoder which have the tunnel junction, ensure rotation of magnetic directions of the free-side magnetic layer, and have good sensitivity.

A third object of the present invention is to provide a magnetic head which is adaptable to higher density of magnetic record mediums, and a hard disk device of a large storage capacity using the magnetic head.

[DISCLOSURE OF THE INVENTION]

The above-described objects are achieved by a magnetic sensor including a ferromagnetic tunnel junction, comprising: a free layer a magnetic direction of which freely rotates; and a barrier layer formed on the free layer and having a smaller thickness in a first region, a region of the free layer corresponding to the first region functioning as a sensor portion for sensing an external magnetic field. Rotation of magnetic directions in the free layer in a region corresponding to the first region can be secured enough. The magnetic sensor can have good sensitivity.

In the above-described magnetic sensor it is possible

that the barrier layer is formed by oxidizing the surface of a metal.

In the above-described magnetic sensor it is possible that further comprising: a fixed layer formed on the barrier layer; and a antiferromagnetic layer formed on the fixed layer and fixing a magnetic direction of the fixed layer.

In the above-described magnetic sensor it is possible that the free layer in a region where the fixed layer is not formed is bent away from the fixed layer.

The above-described objects are achieved by a magnetic head comprising the magnetic sensor. Magnetic heads of high sensitivity can be provided.

The above-described objects are achieved by a magnetic encoder comprising the magnetic sensor. Magnetic encoders of high sensitivity can be provided.

The above-described objects are achieved by a magnetic head comprising a ferromagnetic tunnel junction element including a free layer a magnetic direction of which freely rotates, and a fixed layer which is opposed to one surface of the free layer through a barrier layer and a magnetic direction of which is fixed by a antiferromagnetic layer which is adjacent thereto, the free layer being connected to a member of high permeability. Magnetic heads which are adaptable to high recording density of magnetic storage mediums can be provided.

In the above-described magnetic head it is possible that the free layer is connected to the member of high permeability in a region spaced from a signal detection surface.

In the above-described magnetic head it is possible that the free layer is connected smoothly to the member of high permeability, neighboring the same.

In the above-described magnetic head it is possible that the member of high permeability is a shield layer formed, spaced from the ferromagnetic tunnel junction element.

In the above-described magnetic head it is possible that a thickness of the barrier layer near the edge of the fixed layer is larger than a thickness of the barrier layer near a central part of the fixed layer.

In the above-described magnetic head it is possible that the free layer is formed wider in a region spaced from the signal detection surface.

In the above-described magnetic head it is possible that the fixed layer is not exposed to the signal detection surface.

In the above-described magnetic head it is possible that the member of high permeability is grounded.

In the above-described magnetic head it is possible that the free layer in a region which is not opposed to the fixed layer is bent away from the fixed layer.

In the above-described magnetic head it is possible that the ferromagnetic tunnel junction element further includes another fixed layer which is opposed to the free layer through another barrier layer formed on the other surface of the free layer, a magnetic direction of said another fixed layer being fixed by another antiferromagnetic layer which is adjacent thereto.

The above-described objects are achieved by a hard disk device comprising the magnetic head. Hard disk devices of large storage capacities can be provided.

The above-described objects are achieved by a disk array device comprising a plurality of the hard disk devices. Disk array devices of large storage capacities can be provided.

[BRIEF DESCRIPTION OF THE DRAWINGS]

FIGs. 1A and 1B are views explaining the ferromagnetic tunnel structure. FIG. 1A shows a layer structure having the ferromagnetic tunnel structure, and FIG. 1B is a schematic view explaining measurement of resistance changes of the ferromagnetic tunnel structure shown in FIG. 1A.

FIG. 2 is a graph of magnetic field - resistance characteristics of the tunnel junction shown in FIG. 1.

FIG. 3 is a conceptual view of the GMR effect.

FIG. 4 is a sectional view of a layer film of a spin valve structure.

FIG. 5 is a perspective view explaining an operational principle of a magnetic head using the spin valve structure.

FIG. 6 is a schematic view of magnetic directions of the free layer at the time when a recording bit comes near.

FIGs. 7A and 7B are views explaining a constitution of a spin valve element including the spin valve structure having a tunnel junction. FIG. 7A shows a spin valve element according to a first embodiment of the present invention, and FIG. 7B shows the previously proposed spin valve element as a control.

FIG. 8 is a view showing a constitution of the magnetic sensor according to the first embodiment of the present invention.

FIG. 9 is views explaining a first method for fabricating the magnetic sensor shown in FIG. 8 (Part 1).

FIG. 10 is views explaining the first method for fabricating the magnetic sensor shown in FIG. 8 (Part 2).

FIG. 11 is views explaining a second method for fabricating the magnetic sensor shown in FIG. 8 (Part 1).

FIG. 12 is views explaining the second method for fabricating the magnetic sensor shown in FIG. 8 (Part 2).

FIG. 13A is a view showing a magnetic sensor, FIG. 13B is a view of an equivalent circuit of the magnetic sensor, and FIG. 13C is a view explaining a mask used in the magnetic sensor fabrication.

FIG. 14A is a view showing output characteristics of the magnetic sensor, and FIG. 14B is a view explaining an operational principle of the magnetic sensor.

FIG. 15A is an equivalent circuit used in explaining an operational principle of the magnetic sensor, and FIG. 15B is a view showing output characteristics of the magnetic sensor.

FIG. 16A is a view of an actual magnetic encoder, and FIG. 16B is an enlarged view of a magnetic sensor of the magnetic encoder.

FIG. 17 is sectional views of the magnetic head according to a second embodiment of the present invention.

FIG. 18 is a schematic view of magnetic directions of the free layer at the time when a record bit comes near.

FIG. 19 is a sectional view of an example of the magnetic head according to the second embodiment of the present invention (Example 1).

FIG. 20 is a sectional view of another example of the magnetic head according to the second embodiment of the present invention (Example 2).

FIG. 21 is sectional views of further another example of the magnetic head according to the second embodiment of the present invention (Example 3).

FIG. 22 is a sectional view of the magnetic head according to a third embodiment of the present invention.

FIG. 23 is a side view of the magnetic head according

to a fourth embodiment of the present invention.

FIG. 24 is a plan view of the magnetic head according to a fifth embodiment of the present invention.

FIG. 25 is a plan view of an example of the magnetic head according to the fifth embodiment of the present invention.

[BEST MODES FOR THE CARRYING OUT THE INVENTION]

(A First Embodiment)

The magnetic sensor according to a first embodiment of the present invention, and an embodiment of a method for fabricating the magnetic sensor will be explained with the drawings attached hereto. In the drawings the same members are represented by the same reference number not to repeat explanation.

(Magnetic Sensor)

Here, a typical example of the magnetic sensor will be explained by means of the magnetic sensor having the spin valve structure. FIG. 7A is a view of a structure of the magnetic sensor according to the present embodiment, which has the spin valve structure and uses a tunnel junction. FIG. 7B shows, as a control, the structure of the magnetic sensor having the previously proposed spin valve structure.

As shown in FIG. 7A, the magnetic sensor according to the present embodiment has a tunnel junction of the spin valve structure disposed between a lower magnetic electrode

2 and an upper magnetic electrode 9. The spin valve structure has a layer structure including a barrier layer 11 disposed between the lower layer 10 and the upper layer 12.

As will be detailed with reference to FIG. 8, this spin valve structure generally includes at least a magnetic layer on the free-side as the lower layer 10 and a first magnetic metal layer, and, as the upper layer 12, at least a second magnetic metal layer, a magnetic layer on the fixed-side and an antimagnetic layer. A thin insulation layer as the barrier layer 11 is disposed between the two magnetic metal layers. As shown in FIG. 8, a sensor portion 13 is formed in a region near the central part of the spin valve structure.

As an external magnetic field, a signal magnetic field H_{sig} from a storage medium, such as a magnetic disk, is applied from below as viewed in the drawing to rotate magnetic directions of the free-side magnetic layer.

One characteristic of the magnetic sensor according to the present embodiment is that, as shown in FIG. 7A, the senor portion 13 for a signal magnetic field is limited to a part of the substantially central part of the tunnel junction having the spin valve structure (a region $L \times h_s$ of a part of the magnetic layers).

As will be explained later, a size of the region of the sensor portion 13 is substantially equal to a size (h

× L) of a region of the magnetic layers of the magnetic sensor which will be explained with reference to FIG. 7B. Accordingly, in the magnetic sensor according to the present embodiment the magnetic layers contain the sensor portion 13 at a part thereof, and a size of the magnetic layers is larger relative to that of the magnetic layers of the conventional magnetic sensor shown in FIG. 7B.

In the structure of the magnetic sensor having the previously proposed spin valve structure shown in FIG. 7B, the spin valve structure is disposed between a lower magnetic pole 20 and an upper magnetic pole 90. The layer structure of this conventional spin valve structure is the same as that of the spin valve structure shown in FIG. 7A, and includes a barrier layer 110 disposed between a lower layer 100 and an upper layer 120. The lower layer 100 and the upper layer 120 have the same layer structures as those explained with reference to FIG. 7A.

Similarly, a signal magnetic field H_{sig} from a record medium, such as a magnetic disk as an external magnetic field is applied from below as viewed in the drawing to rotate magnetic directions of the free-side magnetic layer. In the magnetic sensor having the conventional spin valve structure, a sensor portion 130 for a signal magnetic field H_{sig} is a part sandwiched by two insulation layers 150-1, 150-2 (the entire magnetic layers, i.e., h × L).

The magnetic sensor according to the present

embodiment shown in FIG. 7A and the previously proposed magnetic sensor shown in FIG. 7B will be compared with each other. The sizes of both sensor portions 13, 130 are substantially equal to each other. However, the sensor portion 13 of the former (the present embodiment) is limited to a region which is a part of the magnetic layers while the sensor portion 130 of the latter (Control) is the entire magnetic layers. This is a difference between the two magnetic sensors.

The magnetic sensor 13 according to the present embodiment can set the sensor portion 13 at an arbitrary part of the magnetic layers by using the structure shown in FIG. 7A. Here, it is most preferable to set the sensor portion 13 near the substantially central part of the magnetic layers where magnetic directions of the free-side magnetic layer (one layer of the lower layer 10) can most easily rotate. Otherwise, the sensor portion 13 may be formed at a part of the magnetic layers which is as near a measured signal magnetic field as possible. Otherwise, the sensor portion 13 may be formed at a portion where magnetic directions of the magnetic layer can easily rotate.

In the magnetic sensor according to the present embodiment, because the sensor portion 13 is a part of the substantially central part of the magnetic layers, respective magnetic domains of the sensor portion 13 can freely rotate free from influence of a dimension of the

height of the magnetic layers in the direction of the device height h. That is, because a height h_s of the sensor portion 13 is a part of a height h of the magnetic layers, the magnetic domains can freely rotate corresponding to external signal magnetic fields H_{sig} even near the edge of the sensor portion 13. Furthermore, because the magnetic layers are larger for the size of the sensor portion, influences, antimagnetic fields, etc. due to a device configuration can be decreased.

In contrast to this, in the previously proposed magnetic sensor (see FIG. 7B), the entire region of the free-side magnetic layer is the sensor portion 130, whereby respective magnetic domains of the sensor portion 130 do not easily rotate under influence of a dimension h (=h_s) in the direction of the height of the magnetic layers.

FIG. 8 is a detailed sectional view of the magnetic sensor according to the present embodiment shown in FIG. 7A. A layer structure of the magnetic sensor includes a substrate 1, a lower layer 10 formed on the substrate, and a barrier layer 11 formed on the lower layer, and an upper layer 12 formed on the barrier layer.

The lower layer 10 includes a lower electrode 2, a free-side magnetic layer (a lower layer and free layer) 3, and a first magnetic metal layer 4 formed on the free-side magnetic layer. The barrier layer 11 includes an insulation layer 5. The upper layer 12 includes a second

magnetic metal layer 6 formed on the insulation layer 5, a fixed-side magnetic layer 7 formed on the second magnetic metal layer, an antiferromagnetic layer 8 formed on the fixed-side magnetic layer, and an upper electrode 9 formed on the antiferromagnetic layer.

The insulation layer 5 has a region at a part of the central part thereof, which has a film thickness reduced relative to a film thickness of the rest part thereof. Accordingly, the second magnetic metal layer 6 formed on the insulation film 5 has a flat upper surface but a central portion of corresponding to the thickness-reduced central part of the insulation film 5, which increases a thickness downward in comparison with the rest part thereof, forming a downward convexity. The concavity formed in the insulation film 5 is some angstroms. A region corresponding to the central concavity (concave region) 16 forms the sensor portion 13, which has been explained with reference to FIG. 7A.

The respective members of the magnetic sensor will be explained.

The substrate 1 is formed of preferably an Si substrate with a natural oxide film formed on.

The lower electrode 2 is formed of preferably an about 50 nm-thickness Ta film.

The free-side magnetic layer 3 is formed of preferably an about 17 nm-thickness NiFe film.

The first magnetic metal layer 4 is formed of preferably an about 3.3 nm-thickness Co film.

The insulation film 5 is formed of a some angstroms (Å) to tens Å thickness aluminum oxide film. In the present embodiment, the concave portion 16 is formed of an about 1.3 nm-thickness aluminum oxide film and the rest part is formed of an about 3.3 nm-thickness aluminum oxide film.

The second magnetic metal layer 6 is formed of preferably an about 3.3 nm-thickness Co film as is the first magnetic metal layer 4. The first and the second magnetic metal layers 4, 6, the Co film of which have higher polarizability than that of the NiFe film (of the free-side magnetic layer 3 or the fixed-side magnetic layer 7), are provided to lay the Co film on the free-side magnetic layer 3 or the fixed-side magnetic layer 7 to thereby attain high MR ratio.

The fixed-side magnetic layer 7 is formed of preferably an about 17 nm-thickness NiFe film, as is the free-side magnetic layer 3.

The antiferromagnetic layer 8 is formed of preferably an about 50 nm-thickness FeMn film.

The upper electrode 9 is formed of preferably an about 50 nm-thickness Ta film, as is the lower electrode 2.

The magnetic sensor according to the present embodiment uses TMR (tunnel MR) provided by applying a

ferromagnetic tunnel junction to a spin valve structure. The spin valve structure has the Co layers 4, 6 disposed between two magnetic layers (i.e., the free-side magnetic layer 3 and the fixed-side magnetic layer 7), and the antiferromagnetic layer 8 provided on the upper surface of the fixed-side magnetic layer 7 so as to fix a magnetic direction of the fixed-side magnetic layer 7 and the second magnetic metal layer 6 alone. The ferromagnetic tunnel junction has the thin oxide film 5 as the barrier layer 11 disposed between the two ferromagnetic layers 3, 7 (more specifically the first and the second magnetic metal layers 4, 6).

The function of the magnetic sensor according to the present embodiment will be explained. The insulation layer 5 has a reduced thickness at the sensor portion 13, which is smaller relative to that of the rest part thereof. Tunnel resistance R in the direction of thickness of the insulation layer 5 much depends on a thickness of the insulation layer 5 as expressed below.

$R \propto t \times \exp[t]$ .... (4)

where t represents a thickness of the insulation layer.

Accordingly, when direct current is applied between the lower electrode 2 and the upper electrode 9, tunnel current 18 flows concentratedly through the region where the insulation layer 5 is thin. That is, the direct current flows from the upper electrode 9 to the lower

electrode 2 through regions of the respective layers from the antiferromagnetic layer 8 to the free-side magnetic layer 3, which (regions) correspond to the thickness-reduced region 16 of the insulation layer 5. Consequently, the regions corresponding to the concavity 16 having the reduced thickness substantially functions as the sensor portion 13.

As described above, in the ferromagnetic tunnel junction, a tunnel resistance R can be expressed by the formula (1) when a relative angle between magnetic directions of the magnetic layers on both sides is represented by θ. That is, magnetic directions of the free-side magnetic layer 3 and the magnetic metal layer 4 rotate corresponding to an external signal magnetic field H_{sig}, and a tunnel resistance R, which is determined by a relative angle θ between magnetic directions of the magnetic metal layers 4, 6 on both sides, changes. As explained with reference to FIG. 1B, when a certain direct current is applied between the lower electrode 2 and the upper electrode 9, a corresponding tunnel resistance R can be detected as a voltage value. Thus, the magnetic sensor can detect the external signal magnetic field H_{sig}.

As shown in FIGs. 8 and 7A, the sensor portion 13 is formed in a partial region of the magnetic layers. Preferably, the sensor portion 13 is formed substantially at the central part of the magnetic layers. A size of the

sensor portion 13 is the same as that of the magnetic layer region (i.e., the sensor portion 130 in FIG. 7B) of the above-proposed magnetic sensor. Accordingly, the sensor portion 13 can be formed at a proximal location in the magnetic layer region. Otherwise, the sensor portion 13 can be formed substantially at the central part of the magnetic layers. Otherwise, the sensor portion 13 can be formed at a location which is near a measured signal magnetic field as much as possible. Consequently, in the free-side magnetic layer 3, magnetic directions can rotate in respective magnetic domains without influence of the edges of the magnetic layers.

(Method for Fabricating the Magnetic Sensor)

The method for fabricating the magnetic sensor explained with reference to FIGs. 7A and 8 will be explained with reference to FIG. 9A to FIG. 12C. The method for fabricating the magnetic sensor is varied by different methods for forming the thin insulation layer region. A first fabrication method will be explained with reference to FIG. 9A to FIG. 10C, and a second fabrication method will be explained with reference to FIG. 11A to FIG. 12C.

(A First Fabrication Method)

FIG. 9A to FIG. 10C are views continuously explaining the first fabrication method.

As shown in FIG. 9A, an Si substrate 1 with a natural

oxide film formed on is prepared. An about 50 nm-thickness Ta film is formed on the substrate 1 by sputtering. The Ta film functions as the lower electrode 2 when the device is completed. An about 17 nm-thickness NiFe film is formed on the lower electrode 2 with an about 300 (Oe) magnetic field being applied, and furthermore, an about 3.3 nm-thickness Co film is formed. When the device is completed, the free-side magnetic layer (the lower layer, the free layer) 3 of the NiFe film, and the first magnetic metal layer 4 of the Co film function as the free layer.

As shown in FIG. 9B, a resist 19 is applied to the sensor portion 13, and then, an about 2.0 nm-thickness Al film 5-0 which is to function as the insulation layer 5 is formed on the resist 19 and the first magnetic metal layer 4.

As shown in FIG. 9C, the surface of the Al film is oxidized by plasma oxidation to form a first aluminum oxide film 5-1 (i.e., Al-Al_2O_3 film). Then, the resist 19 is removed. The aluminum oxide film is to be the thin insulation film 5, which will function as the tunnel barrier after the device is completed.

As shown in FIG. 9D, again an about 1.3 nm-thickness Al film is formed. Similarly, the surface of the Al film is oxidized by plasma oxidation to form the second aluminum oxide film 5-2. Thus, the insulation film 5 of the first aluminum oxide film 5-1 and the second aluminum oxide film

5-2 has an about 1.3 nm-thickness at the sensor portion 13 and an about 3.3 nm-thickness at the rest part. The region of the insulation film 5 which has the reduced thickness functions as the tunnel barrier after the device is completed.

As shown in FIG. 10A, a 3.3 nm-thickness Co film is formed on the thin insulation film 5.

Then, an about 17 nm-thickness NiFe film is formed on the Co film. Furthermore, an about 50 nm-thickness FeMn film is formed. When the device is completed, the second magnetic metal layer 6 of the Co film and the fixed-side magnetic layer 7 of the NiFe film are the pin layer (fixed layer), and the FeMn film functions as the antiferromagnetic layer 8.

As shown in FIG. 10B, part except the device portion is removed by ion milling, RIE (reactive ion etching) or others, and the insulation layers 15-1, 15-2 are formed a the removed part. Then, an about 50 nm-thickness Ta film is formed on the insulation layers 15-1, 15-2 and the antiferromagnetic layer 8. The Ta film functions as the upper electrode 9 when the device is completed. The insulation layers 15-1, 15-2 are provided for prohibiting the upper electrode 9 and the lower electrode 2 from contacting each other directly or via the edge surfaces.

As shown in FIG. 10C, in the thus-fabricated magnetic sensor, when sense current (a certain direct current) 17 is

applied from the upper electrode 9 to te lower electrode 2, tunnel current passing through the insulation film 5 of aluminum oxide flows concentratedly on the relatively thin portion. This portion functions as the sensor portion 13. The thickness reduced portion can be formed at an arbitrary part within the magnetic layers, preferably at substantially central part of the free-side magnetic layer 3 where magnetic domains of the free-side magnetic layer 3 can most easily rotate, whereby smooth rotation of the magnetic domains can be ensured.

(A Second Fabrication Method)

FIGs. 11A to 12C are view continuously explaining a second fabrication method of the magnetic sensor. The second fabrication method is different from the first fabrication method in the steps of forming the thin insulation film.

As shown in FIG. 11A, an Si substrate 1 with a natural oxide film formed on is prepared. An about 50 nm-thickness Ta film is formed on the substrate 1 by sputtering. The Ta film functions as the lower electrode 2 when the device is completed. An about 17 nm-thickness NiFe film is formed on the lower electrode 2 with an about 300 (Oe) magnetic field being applied, and furthermore, an about 3.3 nm-thickness Co film is formed. When the device is completed, the free-side magnetic layer 3 of the NiFe film, and the first magnetic metal layer 4 of the Co film function as the free

layer. The steps up to here are the same as those of the first fabrication method.

As shown in FIG. 11B, a resist 21 is applied to the sensor portion 13. Then, an about 2.0 nm-thickness first Al_2O_3 film 5-1 is formed on the resist and the first magnetic metal layer 4.

As shown in FIG. 11C, the resist 21 is removed, and then an about 1.3 nm-thickness Al film is formed, and the surface of the Al film is oxidized by plasma oxidation to form an aluminum oxide film (a second Al_2O_3 film) 5-2. Thus, the insulation layer 5 formed of the first aluminum oxide film 5-1 and the second aluminum oxide film 5-2 has an about 1.3 nm-thickness at the sensor portion 13 and an about 3.3 nm-thickness at the rest part. The partially thickness reduced part of the insulation film 5 functions as the tunnel barrier when the device is completed.

Then, the same fabrication steps as those of the first fabrication method follow. That is, as shown in FIG. 12A, an about 3.3 nm-thickness Co film as the second magnetic metal layer 6 is formed on the thin insulation film 5. Then, an about 17 nm-thickness NiFe film 7 as the fixed-side magnetic layer 7 is formed on the second magnetic metal layer 6. Furthermore, an about 50 nm-thickness FeMn film as the antiferromagnetic layer 8 is formed on the fixed-side magnetic layer 7.

As shown in FIG. 12B, the part except the device part

is removed by ion milling, RIE or other technique, and an insulation layers 15-1, 15-2 are formed at the removed part. Then, an about 50 nm-thickness Ta film as the upper electrode 9 is formed on the insulation layers 15-1, 15-2 and the antiferromagnetic layer 8.

In the thus-fabricated magnetic sensor, when sense current (a certain direct current) 17 is applied from the upper electrode 9 to te lower electrode 2, tunnel current passing through the insulation film 5 of aluminum oxide flows concentratedly on the relatively thin sensor portion 13. This portion functions as the sensor portion 13. The thickness reduced portion can be formed at an arbitrary part within the magnetic layers, preferably at substantially central part where magnetic domains of the free-side magnetic layer 3 can most easily rotate, whereby smooth rotation can be ensured in these magnetic domains.

(Application Example to Magnetic Head)

The above-described magnetic sensor is typically applicable to magnetic heads. Recently as a magnetic head, a composite-type magnetic head using as the magnetic head an inductive head for recording, and a GMR head for reproduction which are integrated with each other has been developed and is practically used.

The GMR head typically has the spin valve structure (but has no tunnel junction). In place of the GMR head of the composite-type magnetic head, the magnetic sensor of

the spin valve structure having the above-described tunnel junction is applicable as it is.

(Other Application Examples)

An example of the application of the magnetic sensor according to the present invention to a magnetic encoder will be explained.

FIG. 13A is a view showing the magnetic sensor 50 according to the present invention, which is applied to a magnetic encoder. The magnetic sensor 50 includes an electric source terminal V, a ground terminal GND, an output A-terminal A-OUT and an output B-terminal B-OUT. As the magnetic sensor 50, a first ferromagnetic tunnel junction element TMR_1 is jointed inserted between the electric source terminal V and the output A-terminal A-OUT, a second ferromagnetic tunnel junction element TMR_2 is inserted between the electric source terminal V and the output B-terminal B-OUT, a third ferromagnetic tunnel junction element TMR_3 is inserted between the ground terminal GND and the output A-terminal A-OUT, and a fourth ferromagnetic tunnel junction element TMR_4 is inserted between the ground terminal GND and the output B-terminal B-OUT.

Each of the ferromagnetic tunnel junction elements (i.e., TMR_1 to TMR_4) has 6 tunnel junctions (51-1 to 51-6, 52-1 to 52-6, 53-1 to 53-6, 54-1 to 54-6) which are serially connected. Each of the tunnel junctions 51-1 to

54-6 has an about 50 μm × 50 μm junction area.

FIG. 13B is a circuit diagram equivalent to the magnetic sensor 50 shown in FIG. 13A.

A method for fabricating the magnetic sensor shown in FIG. 13A will be briefly explained. First, using the mask shown in FIG. 13C an about 17 nm-thickness NiFe film as the free-side magnetic layer is formed, and continuously, an about 3.3 nm-thickness Co film is formed as a first magnetic metal layer.

The mask is replaced, and then an about 1.3 nm-thickness Al film is formed as an insulation layer, and the surface of the Al film is oxidized. The oxidation is performed by the plasma oxidation explained in the first and the second fabrication methods to form a thinner oxide film at the sensor portion and a relatively thick oxide film in the rest region. The oxidation may be performed by, e.g., natural oxidation.

After the formation of the oxide film, the mask is replaced, and an about 3.3 nm-thickness Co film as a second magnetic metal film is formed, an about 17 nm-thickness NiFe film as a fixed-side magnetic layer is formed, and an about 45 nm-thickness FeMn film as an antiferromagnetic layer is formed. Furthermore, an about 8 nm-thickness Ta film as an upper electrode is formed. Thus, the magnetic encoder can be formed of the same layer structure as the spin valve-type magnetic sensor and can be fabricated by

the same fabrication steps as the spin valve-type magnetic sensor.

Next, the operation of the magnetic encoder will be explained.

FIG. 14A is a view schematically showing a magnetoresistance curve of the magnetic encoder shown in FIG. 13A. As explained with reference to Formula (1), a magnetic direction M_{upper} of the upper layer 12 of the ferromagnetic tunnel junction element TMR is fixed by the antiferromagnetic layer (FeMn film) 8 so that a magnetic direction M_{lower} of the lower layer 10 is orthogonal to a magnetic direction M_{lower} of the lower layer 10. As shown in FIG. 14A, when an external magnetic field is applied to the ferromagnetic tunnel junction element TMR in the same direction as a magnetic direction M_{upper} of the upper layer 12 (i.e., an external magnetic field -H), a magnetic direction M_{upper} of the upper layer 12 and that M_{lower} of the lower layer 10 are parallel with each other in the same direction. That is, a relative angle θ between the two magnetic directions is 0°, and, based on Formula (1), a resistance value of the ferromagnetic tunnel junction element TMR is minimum, and $R=R_s$. A minimum resistance value at this time is represented by R_L.

When an external magnetic field is zero for the ferromagnetic tunnel junction element TMR, a magnetic direction M_{lower} of the lower layer 10 rotates, and a

relative angle θ between magnetic directions of the upper layer 12 and the lower layer 10 is 90°. Based on Formula (1), a resistance value of the ferromagnetic tunnel junction element TMR is $R=R_s+0.5\times\Delta R$. A resistance value given when an external magnetic field is zero is represented by R_0.

When an external magnetic field is applied to the ferromagnetic tunnel junction element TMR in a direction opposite to a magnetic direction M_{upper} of the upper layer 12 (i.e., an external magnetic field H), a magnetic direction M_{lower} of the lower layer 10 rotates, and a magnetic direction of M_{upper} of the upper layer 12 and a magnetic direction M_{lower} of the lower layer 10 are parallel with each other in opposite directions. That is, relative angle θ is 180°, based on Formula (1), a resistance value of the ferromagnetic tunnel junction element TMR is maximum, and $R=R_s+\Delta R$. A maximum resistance value at this time is represented by R_H.

Thus, when an external magnetic field is -H, 0, +H, a resistance value of the ferromagnetic tunnel junction element TMR is R_L, R_0 and R_H, and $R_L<R_0<R_H$. FIG. 14A graphs this relationship.

FIG. 14B is a view explaining an operational principle of the encoder. A magnetic field generating magnet to be measured 55 and a magnetic sensor 50 formed of tunnel junction elements TMR have the positional relationship with

each other as shown. The magnetic field generating magnet 55 is an elongate magnetic body magnetized alternately with N pole and S pole, and a gap between the S and N poles of one pair is λ. The TMR_1 to the TMR_4 of the magnetic sensor 50 are arranged near the magnetic field generating magnet 55 relatively displaceably in the longitudinal direction of the magnetic field generating magnet 55 and in parallelism therewith.

That is, initially, the magnetic sensor 50 including the tunnel junction elements TMR_1 to TMR_4 is located at a sensor position [1]. The respective ferromagnetic tunnel junction elements TMRs are arranged at a $\lambda/4$ gap. After a ceratin time t determined by a displacement speed, the magnetic sensor 50 is displaced right by $\lambda/4$ parallelly with the magnet 55 to located at the sensor position [2]. In the drawing, however, the sensor position [2] is shown away from the magnetic field generating magnet 55 because if the sensor position [2] is shown, overlapping the sensor position [1], the drawing will make the understanding difficult. It should be noted that actually the magnetic sensor 55 is relatively displaced in the longitudinal direction of the magnetic field generating magnet 55 in parallelism therewith over a position near the magnet 55. This is true with the sensor positions [3] and [4].

Furthermore, after the time t, the magnetic sensor 50 at the sensor position [2] is located at the sensor

position [3], and then after the time t, the magnetic sensor 50 is located at the sensor position [4]. Thus the magnetic sensor 50 makes the parallel displacement.

First, at the sensor position [1] in FIG. 14B, the respective tunnel junction elements have $TMR_1=R_L$, $TMR_2=R_0$, $TMR_3=R_H$ and $TMR_4=R_0$ under the influence of an external magnetic field from the magnetic field generating magnet 55. FIG. 15A corresponds to FIG. 13B. In this equivalent circuit, the voltage output V_A and the voltage output V_B of the output A-terminal and the output B-terminal respectively divide a voltage V to the TMR_1 and the TMR_3 and a voltage V to the TMR_2 and the TMR_4. The following formula is obtained.

$V_A = V \times TMR_3 / (TMR_1 + TMR_3)$

$= V \times R_H / (R_L + R_H)$ .... (5)

$V_B = V \times TMR_4 / (TMR_2 + TMR_4)$

$= V \times R_0 / (R_0 + R_0)$ .... (6)

Here, the following formulas are derived from the results of Formulas (5) and (6).

$V_A = V \times R_H / (R_L + R_H) = V_H$ .... (7)

$V_B = V \times R_0 / (R_0 + R_0) = V / 2 = V_0$ .... (8)

Then, at the sensor position [2] in FIG. 14B,

$TMR_1 = R_0$, $TMR_2 = R_H$, $TMR_3 = R_0$, $TMR_4 = R_L$

Accordingly, voltage outputs V_A, V_B of the output A-terminal and the output B-terminal are as follows.

$V_A = V \times TMR_3 / (TMR_1 + TMR_3)$

$$= V \times R_O / (R_O + R_O) = V / 2 = V_O \quad .... (9)$$

$$V_B = V \times TMR_4 / (TMR_2 + TMR_4)$$

$$= V \times R_L / (R_H + R_L) \quad .... (10)$$

Here, the following formula can be derived from the result of Formula (10).

$$V_A = V \times R_L / (R_L + R_H) = V_L \quad .... (11)$$

Similarly, at the sensor position [3] in FIG. 14B,

$TMR_1 = R_H$, $TMR_2 = R_O$, $TMR_3 = R_L$, $TMR_4 = R_O$

Accordingly voltage outputs V_A, V_B of the output A-terminal and the output B-terminal are as follows.

$$V_A = V \times TMR_3 / (TMR_1 + TMR_3)$$

$$= V \times R_L / (R_H + R_L) = V_L \quad .... (12)$$

$$V_B = V \times TMR_4 / (TMR_2 + TMR_4)$$

$$= V \times R_O / (R_O + R_O) = V / 2 = V_O \quad ...... (13)$$

Similarly, at the sensor position [4] in FIG. 14B,

$TMR_1 = R_O$, $TMR_2 = R_L$, $TMR_3 = R_O$, $TMR_4 = R_H$

Accordingly, voltage outputs V_A, V_B of the output A-terminal and the output B-terminal are as follows.

$$V_A = V \times TMR_3 / (TMR_1 + TMR_3)$$

$$= V \times R_O / (R_O + R) = V / 2 = V_O \quad .... (14)$$

$$V_B = V \times TMR_4 / (TMR_2 + TMR_4)$$

$$= V \times R_H / (R_L + R_H) = V_H \quad .... (15)$$

Hereafter the magnetic sensor 50 repeatedly takes the sensor positions [1] to [4] with respect to the S and N poles of the magnetic field generating magnet 55. FIG. 15B shows output waveforms of the magnetic sensor 50.

FIG. 16 is views of an actual magnetic encoder using the operational principle explained with reference to FIG. 14. This magnetic encoder includes a rotary magnetic body 56 and a magnetic sensor 50 disposed near the rotary magnetic body 56. Actually the rotary magnetic body 56 is used in place of making the magnetic field generating magnet 55 infinitely elongate.

The rotary magnetic body 56 has a 10 mm-diameter, and the shaft has a 5 mm-diameter. Sixteen pairs of S pole and N pole are arranged radially on the circumferential surface. A magnetic period λ is about 1.5 mm. The magnetic sensor 50 is positioned with the center of the sensor aligned with the center of the radial magnetic portions of the rotary magnetic body 56.

In the magnetic sensor 50 respective ferromagnetic tunnel junction elements TMR must be arranged at λ/4 gap with respect to each other and in parallelism with radially extended magnets of the rotary magnetic body. To this end, the respective TMR elements form an about 5.6° and spaced at the center from each other by a 0.37 mm gap. The thus-formed magnetic encoder can provide by the respective ferromagnetic tunnel junction elements TMR of the magnetic sensor 50 the output waveforms explained with reference to FIG. 15B. That is, when the magnetic sensor 50 is displaced by a magnetic period λ with respect to the rotary magnetic body 56, an output pulse of one period is

generated.

As described in connection with the spin valve magnetic sensor, the sensor portion can be formed at a proximal location in the magnetic layer regions of the tunnel junctions of the respective ferromagnetic tunnel junction elements TMR. Consequently, in the free-side magnetic layer, magnetic directions can easily rotate in respective magnetic domains of the free-side magnetic layer, free from the influence of the edges of the magnetic layer.

As described above, according to the present embodiment, innovational magnetic sensors, magnetic heads and magnetic encoders can be provided.

According to the present embodiment, rotation of magnetic directions of the free-side magnetic layer can be sufficiently ensured. The present invention is applicable generally to magnetic sensors, such as magnetic heads, magnetic encoders, etc.

(A Second Embodiment)

The magnetic head according to a second embodiment of the present invention will be explained with reference to FIG. 17. FIG. 17 is a sectional view of the magnetic head according tot he present embodiment. FIGs. 17B is an enlarged sectional view of the ferromagnetic tunnel junction element of the magnetic head shown in FIG. 17B.

As shown in FIG. 17A, the magnetic head according to

the present embodiment includes a ferromagnetic tunnel junction element 210 whose electric resistance changes corresponding to changes of a magnetic filed from the outside. The ferromagnetic tunnel junction element 210 includes a free layer 214, a barrier layer 216, a fixed layer 218 and an antiferromagnetic layer 220.

As shown in FIG. 17B, the free layer 214 is formed of a 3 nm-thickness NiFe layer 221 and a 3 nm-thickness Co layer 224. The barrier layer 216 is formed of a 1 nm-thickness Al_2O_3 layer adjacent to the Co layer 224 of the free layer 214.

The fixed layer 218 is formed of a 3 nm-thickness Co layer 226 and a 3 nm-thickness NiFe layer 228 adjacent to the barrier layer 216. The ferromagnetic layer 220 is formed of an NiO layer adjacent to the fixed layer 218.

Shield layers 212a, 212b of an NiFe layer are formed, spaced from the ferromagnetic tunnel junction element 210. A non-magnetic layer 222 of an Al_2O_3 layer is formed between the ferromagnetic tunnel junction element 210, and the shield layers 212a, 212b. The lower side as viewed in the drawing is a signal detection surface 230 of the magnetic head.

In the ferromagnetic tunnel junction element 210 having such structure, when a voltage is applied between the fixed layer 218 and the fee layer 214, current flows through the barrier layer 216.

FIG. 17A shows a state that a record bit 232 of a magnetic storage medium is near the ferromagnetic tunnel junction element 210. Actually a number of record bits are formed in a magnetic storage medium but are omitted in FIG. 17A.

When the record bit 232 of a magnetic storage medium comes near the ferromagnetic tunnel junction element 210, a magnetic direction of the free layer 214 rotates. On the other hand, the fixed layer 218, adjacent to which the antiferromagnetic layer 220 is formed, has a magnetic direction fixed.

The magnetic head according to the present embodiment is characterized in that, as shown in FIG. 17A, the free layer 214 is extended away from the signal detection surface 230 and has the end thereof connected to the shield layer 212a, which allows a magnetic flux from the record bit 232 to easily pass through the free layer 214.

In the present embodiment, because the free layer 214 is connected to the shield layer 212a of an NiFe layer, whose permeability is high, a magnetic flux from the record bit 232 easily pass through the free layer 214. In addition, because the free layer 214 is extended away from the signal detection surface 230, the influence of a demagnetizing field in the free layer 214 can be reduced. Thus, a rotation angle of a magnetic direction of the free layer 214 can be large. The free layer 214 is connected

smoothly to the shield layer 212a in a region spaced form the signal detection surface 230, which reduces the influence of the demagnetizing field in the free layer 214.

The change of a magnetic direction of the free layer 214 of the magnetic head according to the present embodiment will be explained with reference to FIG. 18. FIG. 18 is a schematic view of magnetic directions of the free layers at the time when a record bit comes near. The arrows indicate magnetic directions. The region surrounded by the ellipse is a region where magnetization angles of the free layer is above a certain angle. FIG. 18 shows magnetic directions of the free layer in a area which is about 20 μm away from the signal detection surface.

In the magnetic head using a spin valve structure, as the core is micronized, as shown in FIG. 6 the influence of demagnetizing field takes place near the signal detection surface 430 and the upper part of the core 400. Accordingly, a magnetic angle θ_1 of the free layer 414 is small when the record bit 232 comes near, which makes it impossible to obtain high outputs.

In contrast to this, in the present embodiment, the free layer 214 is extended away from the signal detection surface 230, whereby the influence of the demagnetizing field does not easily take place near the region of the junction between the fixed layer 218 and the free layer 214. Accordingly, as shown in FIG. 18, changes of a

magnetic direction of the free layer 214 at the time when the record bit 232 comes near take place even in the region away from the signal detection surface 230, and, in addition, magnetic angles θ_1 can be large.

Accordingly, in the present embodiment, large electric resistance changes, is comparison with those of the conventional magnetic head, can be obtained when the record bit 232 comes near the ferromagnetic tunnel junction element 210, whereby higher detection sensitivity can be provided.

As described above, in the present embodiment, the free layer is extended away from the signal detection surface, and the end of the extended free layer is connected to the shield layer of high permeability, whereby the influence of the demagnetizing field in the free layer can be reduced. Consequently, the influence of the demagnetizing field near the region of junction between the free layer and the fixed layer can be reduced, whereby a rotation angle of a magnetic direction in the junction region can be large, and an electric resistance change at the time when a record bit comes near can be large. Consequently, even in a case that the junction region has a small width, the magnetic head can have sufficiently high detection sensitivity, and is adaptable to higher record densities of magnetic storage mediums.

(Other Examples (Example 1))

One example (Example 1) of the magnetic head according to the second embodiment of the present invention will be explained with reference to FIG. 19. FIG. 19 is sectional views of the magnetic head according to the present example. FIG. 19B is an enlarged sectional view of the ferromagnetic tunnel junction element shown in FIG. 19A.

As shown in FIG. 19, in the present example, a region where the influence of the demagnetizing field is little is the region 234 of junction between a fixed layer 218 and a free layer 214.

That is, in the edge part of the fixed layer 218 rotation angles of magnetic directions small due to the influence of the demagnetizing field taking place there. In the present example, however, the barrier layer 216 is thin in a region near the central part of the fixed layer 218 to an extent that the tunnel junction is possible and is thick in a region near the edge part of the fixed layer 218. Accordingly, the region of the fixed layer 218 except the edge part thereof, i.e., a region where the influence of the demagnetizing field is little is the junction region 234, whereby electric resistance changes of a ferromagnetic tunnel junction elements 210 due to magnetic fields from record bits can be large.

As described above, according to the present example, a region where the influence of demagnetizing fields is little is the junction region, whereby magnetic heads

having high detection sensitivities can ben provided.

(Other Examples (Example 2))

Another example (Example 2) of the magnetic head according to the second embodiment of the present invention will be explained with reference to FIG. 20. FIG. 20 is a sectional view of the magnetic head according to the present example.

As shown in FIG. 20, the present example is the same as the magnetic head according to the second embodiment shown in FIG. 17 in that in the former, a fixed layer 218a is formed of a 2 nm-thickness NiFe layer 228, a 2 nm-thickness Co layer 226, a 1 nm-thickness Ru layer 236 and a 3 nm-thickness Co layer 240.

In the present example, the fixed layer 218a is formed of the layer film of the NiFe layer 228, the Co layer 226, the Ru layer 236 and the Co layer 240, and antiferromagnetic coupling is formed between the Co layer 226 and the Co layer 240, whereby extension of a magnetic filed from the fixed layer 218a to the free layer 214 can be suppressed. Accordingly, shift of a bias point of the free layer can be prevented.

(Other Examples (Example 3))

Further another example (Example 3) of the magnetic head according to the second embodiment of the present invention will be explained with reference to FIG. 21. FIG. 21 is sectional views of the magnetic head according

to the present example. FIG. 21B is an enlarged sectional view of the ferromagnetic tunnel junction element shown in FIG. 21A.

As shown in FIG. 21A, the magnetic head according to the present example is characterized in that a fixed layer 218 is not exposed to a signal detection surface 230, and a shield layer 212a connected to the end of a free layer 214 is grounded.

In the present example, because the fixed layer 218 is not exposed to the signal detection surface 230, even when a potential difference takes place between the fixed layer 218 and the magnetic record medium (not shown), occurrence of discharge can be prevented.

In the present example, the free layer 214 exposed to the signal detection surface 230 is grounded via the shield layer 212a. Accordingly, a magnetic record medium is grounded, whereby no potential difference takes place between the free layer 214 and a magnetic record medium. Accordingly, occurrence of potential difference between the free layer 214 and a magnetic record medium can be prevented, whereby occurrence of discharge from the free layer 214 to the magnetic medium can be prevented. According to the present example, breakage of stored information of record bits due to discharge can be prevented.

In the present example, a junction region 234 between

the fixed layer 218 and the free layer 214 is spaced from the signal detection surface 230. Accordingly, even when the signal detection surface 230 is abraded, it is rare that even the junction region 234 between the fixed layer 218 and the free layer 214 is abraded. Thus, decrease of the junction region 234 between the fixed layer 218 and the free layer 214 can be prevented.

Accordingly, the magnetic head according to the present example is applicable as a contact-type magnetic head which is used in contact with the signal detection surface 230 with a magnetic record medium.

As described above, according to the present example, the fixed layer is not exposed to the signal detection surface, whereby even when a potential difference takes place between the fixed layer and a magnetic record medium takes place, occurrence of discharge can be prevented. The free layer exposed to the signal detection surface is grounded via the shield layer, whereby a magnetic record medium is grounded to thereby make a potential of the free layer and that of a magnetic record medium equal to each other. Accordingly, occurrence of potential difference between the free layer and a magnetic record medium can be prevented, and discharge from the free layer to the magnetic record medium can be prevented, whereby breakage of stored information of record bits of a magnetic record mediums can be prevented.

In the present example, the junction region between the fixed layer and the free layer is spaced from the signal detection surface, whereby even when the signal detection surface is abraded, it is rare that even the junction region between the fixed layer and the free layer is abraded. Accordingly, decrease of the junction region between the fixed layer and the free layer can be prevented. Thus, the present example is applicable to contact-type magnetic heads which is used with the signal detection surface in contact with a magnetic record medium.

(A Third Embodiment)

The magnetic head according to a third embodiment of the present invention will be explained with reference to FIG. 22. FIG. 22 is a sectional view of the magnetic head according to the present embodiment. The same members of the magnetic head according to the present embodiment as those of the magnetic head according to the second embodiment shown in FIGs. 17A to 21 are represented by the same reference numbers not to repeat or to simplify the explanation.

As shown in FIG. 22, the magnetic head according to the present embodiment is characterized in that a ferromagnetic tunnel junction element 210a includes to ferromagnetic tunnel junctions.

That is, a barrier layer 216a which is substantially the same as the barrier layer 216 are formed

plane-symmetrical with respect to the free layer 214. A fixed layer 218b which is substantially the same as the fixed layer 218 are formed plane-symmetrical with respect to the free layer 214. A antiferromagnetic layer 220a which is substantially the same as the antiferromagnetic layer 220 are formed plane-symmetrical with respect to the free layer 214.

When a record bit (not shown) comes near a ferromagnetic tunnel junction element 210a, a magnetic direction of the fixed layer 218 becomes the same as that of the fixed layer 218b.

The ferromagnetic tunnel junction 210a has tow ferromagnetic tunnel junctions, outputs of the two ferromagnetic tunnel junctions are combined to thereby realize high detection sensitivity.

A difference between outputs of the two ferromagnetic tunnel junctions of the ferromagnetic tunnel junction element 210a is detected to thereby cancel noises of the same phase.

As described above, according to the present embodiment, two ferromagnetic tunnel junctions are formed plane-symmetrical with respect to the free layer, whereby outputs of the two ferromagnetic tunnel junctions are combined to thereby realize high-output sensitivity. A difference between outputs of the two ferromagnetic tunnel junctions is detected to thereby cancel noises of the same

phase.

(A Fourth Embodiment)

The magnetic head according to a fourth embodiment of the present invention will be explained with reference to FIG. 23. FIG. 23 is a side view of the magnetic head according to the present embodiment. The same members of the magnetic head according to the present embodiment as those of the magnetic head according to the second or the third embodiment shown in FIGs. 17 to 22 are represented by the same reference numbers not to repeat or to simplify the explanation.

As shown in FIG. 23, the magnetic head according to the present embodiment is characterized by the shape of a free layer 214a. That is, the free layer 214a has a width which is a little larger than a width of a fixed layer 218, near a signal detection surface 230 and a junction region 234 between the fixed layer 218 and the free layer 214a, has the width gradually increased away from the signal detection surface 230, and has a much increased width at a part which is further away from the signal detection surface 230.

In the free layer which is simply formed in a rectangular shape, even when no external magnetic field is applied, a magnetic direction of the free layer is tilted in the longitudinal direction of the free layer. In the present embodiment, however, because the free layer is

formed in the shape as shown in FIG. 23, a magnetic direction of the free layer 214a near the junction region 234 is prevented from tilting when no external magnetic field is applied. Accordingly, when an external magnetic field is applied, a magnetic direction of the free layer 214a sufficiently rotate near the junction region 234, whereby the magnetic head can have high detection sensitivity.

As described above, according to the present embodiment, the free layer is wider away from the signal detection surface and is further wider in a region which is away from the signal detection surface, whereby when no external magnetic field is applied, a magnetic direction of the free layer is prevented from tilting near the junction region. Accordingly a rotation angle of a magnetic direction of the free layer near the junction region can be large, and the magnetic head can have high detection sensitivity.

(A Fifth Embodiment)

A magnetic head according to a fifth embodiment of the present invention will be explained with reference to FIG. 24. FIG. 24 is a plan view of the magnetic head according to the present embodiment as viewed at the side of the signal detection surface. The same members of the magnetic head according to the present embodiment as those of the magnetic head according to the second to the fourth

embodiment shown in FIGs. 17A to 23 are represented by the same reference numbers not to repeat or to simply the explanation.

As shown in FIG. 24, the magnetic head according to the present embodiment is characterized in that a free layer 214b in the region except a junction region 234 between a fixed layer 218 and a free layer 214b is bent to be away from the fixed layer 218.

Because the free layer 214b in the region except the junction region 234 between the fixed layer 218 and the free layer 214b is bent away from the fixed layer 218, even a distance of tracks is small due to high recording density of a magnetic record medium, a magnetic filed from record bits of adjacent tracks is less influential.

As described above, according to the present embodiment, the free layer in the region except the junction region between the fixed layer and the free layer is bent away from the fixed layer, magnetic fields from record bits of adjacent tracks can be made less influential. Thus, magnetic fields from record bits of adjacent tracks can be made less influential, which makes the magnetic head applicable to high recording densities of magnetic storage mediums.

(Other Examples)

One example of the magnetic head according to the fifth embodiment of the present invention will be explained

with reference to FIG. 25. FIG. 25 is a plan view of the magnetic head according to the present example as viewed at the side of the signal detection surface.

As shown in FIG. 25, in the present example, a free layer 214c in the region except a junction region 234 between a fixed layer 218 and the free layer 214c is bent away from the fixed layer 218, and furthermore the bent part of the free layer 214c is bent away from a shield layer 212a. Thus, a spacing between the shield layer 212a and a shield layer 212b can be small, whereby a portion for detecting signals can be micronized. The magnetic head is applicable to higher recording density of magnetic storage mediums.

(Modified Embodiments)

The present invention is not limited to the above-described embodiments and can cover various modifications.

For example, in the first embodiment it is possible that the lower layer 10 functioning the free layer is extended away from the signal detection surface, and the end of the extended lower layer 10 is connected to a shield layer of high permeability. Thus, the influence of the demagnetizing field in the sensor portion 13 can be further decreased, and higher detection sensitivity can be provided.

In the first embodiment it is possible that the lower

layer 10 is formed as the free layer 214b shown in FIG. 24. That is, it is possible that the sensor portion 13 is bent away from the upper layer 12 in the region except the sensor portion 13. Thus, magnetic field from record bits of adjacent tracks can be made less influential, whereby the magnetic head is adaptable to thigh recording density of magnetic storage mediums.

A magnetic head using the magnetic sensor according to the first embodiment is applicable to hard disk devices. The magnetic sensor of such high sensitivity is used, which makes hard disk devices adaptable to high recording density of magnetic storage mediums.

In the second to the fifth embodiments, the free layer is connected to the shield layer, but the free layer may be connected not only to the shield layer, but also suitably to a magnetic body of high permeability.

In the second to the fifth embodiments, the magnetic heads have been explained, but hard disk devices using the above-described magnetic heads can be provided. A plurality of such hard disk devices are used to provide a disk array device.

In the first to the fifth embodiments the free layer and the fixed layer are formed of an NiFe layer and a Co layer. However, materials of the free layer and the fixed layer are not limited to NiFe layer and Co layer. The free layer and the fixed layer may be formed of other layers as

long as they can realize the ferromagnetic tunnel junction.

[INDUSTRIAL APPLICABILITY]

The present invention is suitable for magnetic sensors, magnetic heads, magnetic encoders and hard disk devices, more specifically to magnetic sensors, magnetic heads, magnetic encoders which can realize good sensitivity, magnetic heads which are adaptable to high density of magnetic storage mediums of high density and hard disk devices of large storage capacities using the magnetic heads.

CLAIMS

1. A magnetic sensor including a ferromagnetic tunnel junction, comprising:

a free layer a magnetic direction of which freely rotates; and

a barrier layer formed on the free layer and having a smaller thickness in a first region,

a region of the free layer corresponding to the first region functioning as a sensor portion for sensing an external magnetic field.

2. A magnetic sensor according to claim 1, wherein

the barrier layer is formed by oxidizing the surface of a metal.

3. A magnetic sensor according to claim 1 or 2, further comprising:

a fixed layer formed on the barrier layer; and

a antiferromagnetic layer formed on the fixed layer and fixing a magnetic direction of the fixed layer.

4. A magnetic sensor according to claim 3, wherein

the free layer in a region where the fixed layer is not formed is bent away from the fixed layer.

5. A magnetic head comprising the magnetic sensor according to any one of claims 1 to 4.

6. A magnetic encoder comprising the magnetic sensor according to any one of claims 1 to 4.

7. A magnetic head comprising a ferromagnetic tunnel junction element including a free layer a magnetic direction of which freely rotates, and a fixed layer which is opposed to one surface of the free layer through a barrier layer and a magnetic direction of which is fixed by a antiferromagnetic layer which is adjacent thereto,

the free layer being connected to a member of high permeability.

8. A magnetic head according to claim 7, wherein

the free layer is connected to the member of high permeability in a region spaced from a signal detection surface.

9. A magnetic head according to claim 7 or 8, wherein

the free layer is connected smoothly to the member of high permeability, neighboring the same.

10. A magnetic head according to any one of claims 7 to 9, wherein

the member of high permeability is a shield layer formed, spaced from the ferromagnetic tunnel junction element.

11. A magnetic head according to any one of claim 7 to 10, wherein

a thickness of the barrier layer near the edge of the fixed layer is larger than a thickness of the barrier layer near a central part of the fixed layer.

12. A magnetic head according to any one of claims 7 to 11, wherein

the free layer is formed wider in a region spaced from the signal detection surface.

13. A magnetic head according to any one of claims 7 to 12, wherein

the fixed layer is not exposed to the signal detection surface.

14. A magnetic head according to any one of claims 7 to 13, wherein

the member of high permeability is grounded.

15. A magnetic head according to any one of claims 7 to 14, wherein

the free layer in a region which is not opposed to the fixed layer is bent away from the fixed layer.

16. A magnetic head according to any one of claims 7 to 15, wherein

the ferromagnetic tunnel junction element further includes another fixed layer which is opposed to the free layer through another barrier layer formed on the other surface of the free layer, a magnetic direction of said another fixed layer being fixed by another antiferromagnetic layer which is adjacent thereto.

17. A hard disk device comprising the magnetic head according to any one of claim 5 and claims 7 to 16.

18. A disk array device comprising a plurality of the

hard disk devices according to claim 17.

ABSTRACT

A magnetic sensor including a ferromagnetic tunnel junction, comprises a free layer 10 a magnetic direction of which freely rotates, and a barrier layer 11 formed on the free layer and reduces a thickness in a first region, the free layer in a region corresponding to the first region functioning as a sensor portion for sensing an external magnetic field. Such magnetic sensor can provide magnetic sensors, magnetic heads and magnetic encoders having high sensitivity. Furthermore, such magnetic sensor can provide magnetic heads which are adaptable to high recording density of magnetic storage mediums, and hard disk devices of large storage capacities using the magnetic heads.

FIG. 1A

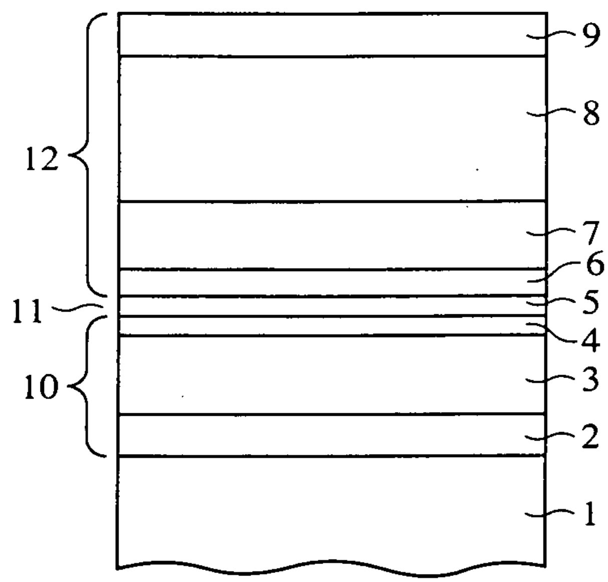


FIG. 1B

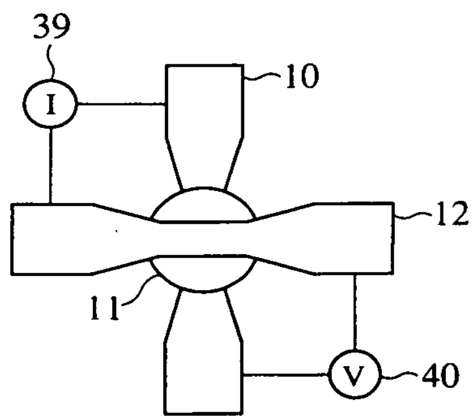


FIG. 2

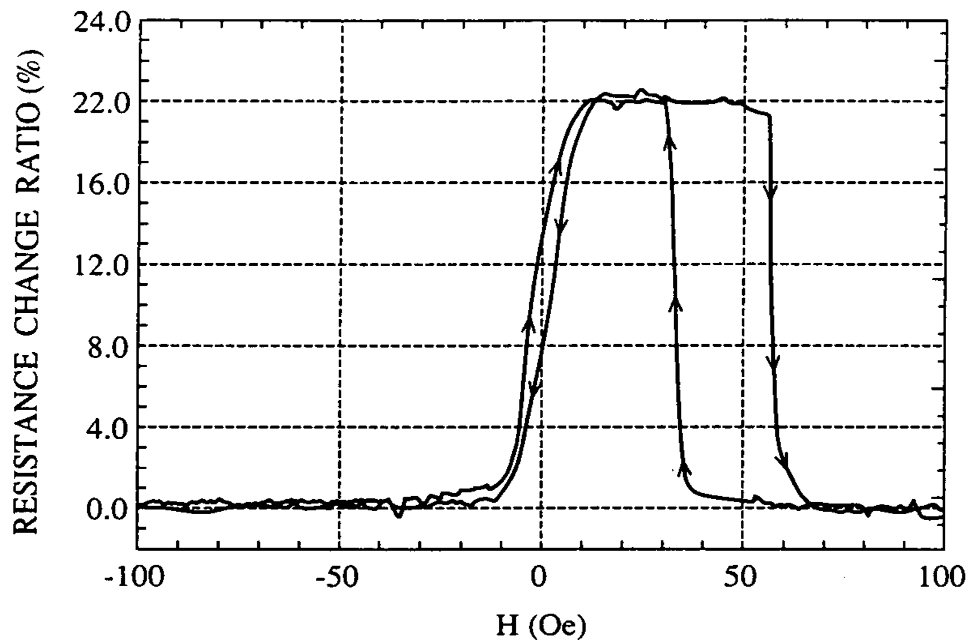

24.0
22.0
16.0
12.0
8.0
4.0
0.0
RESISTANCE CHANGE RATIO (%)
-100
-50
0
50
100
H (Oe)

FIG. 3

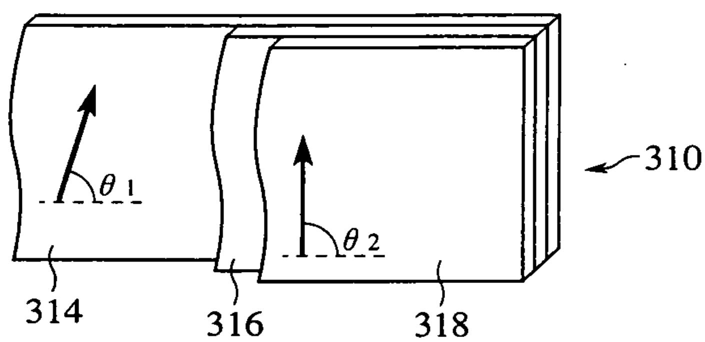


FIG. 4

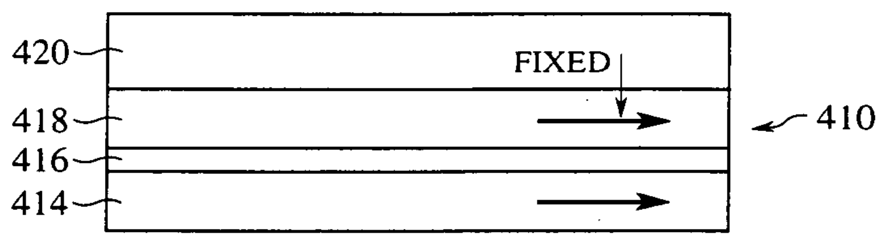


FIG. 5

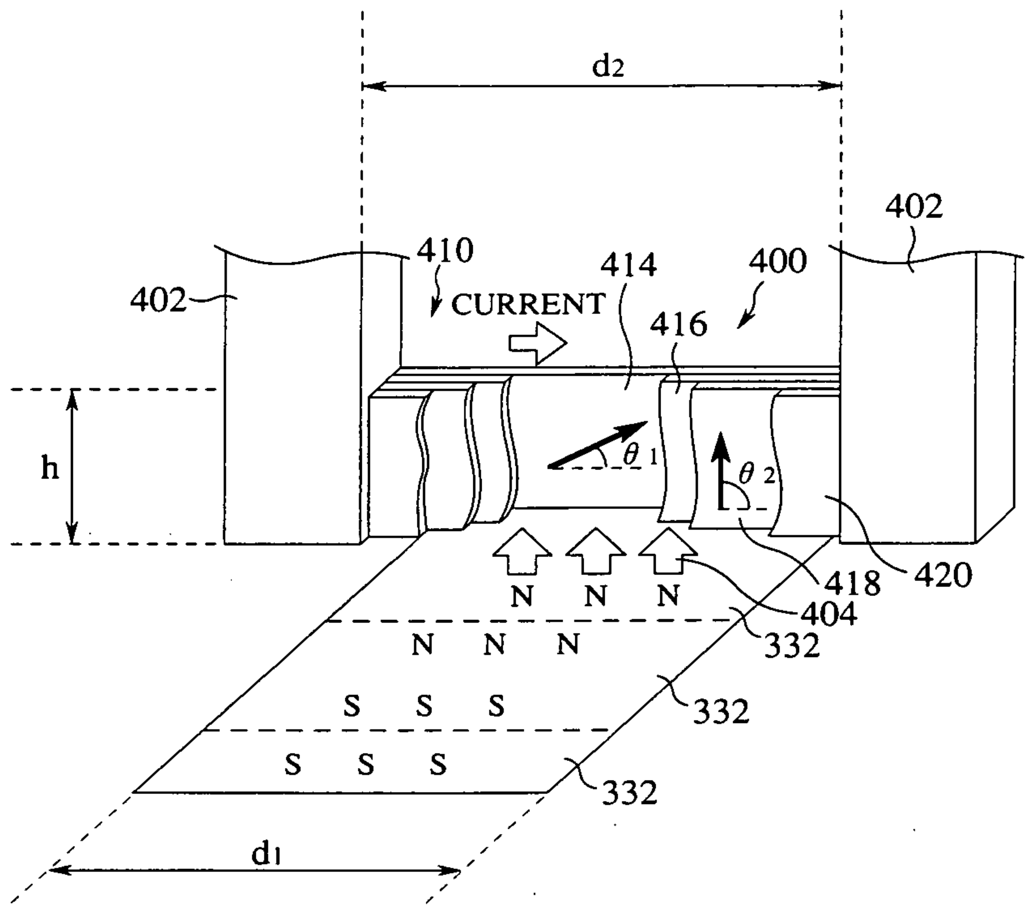

d2
402
410
414
400
402
CURRENT
416
h
θ 1
θ 2
418
420
N N N
404
N N N
332
S S S
332
S S S
332
d1

FIG. 6

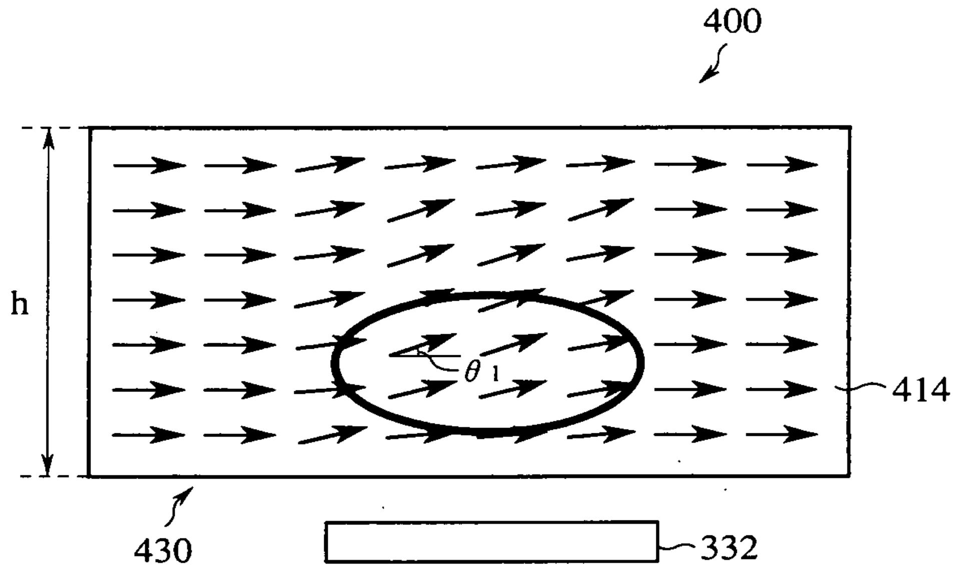


FIG. 7A

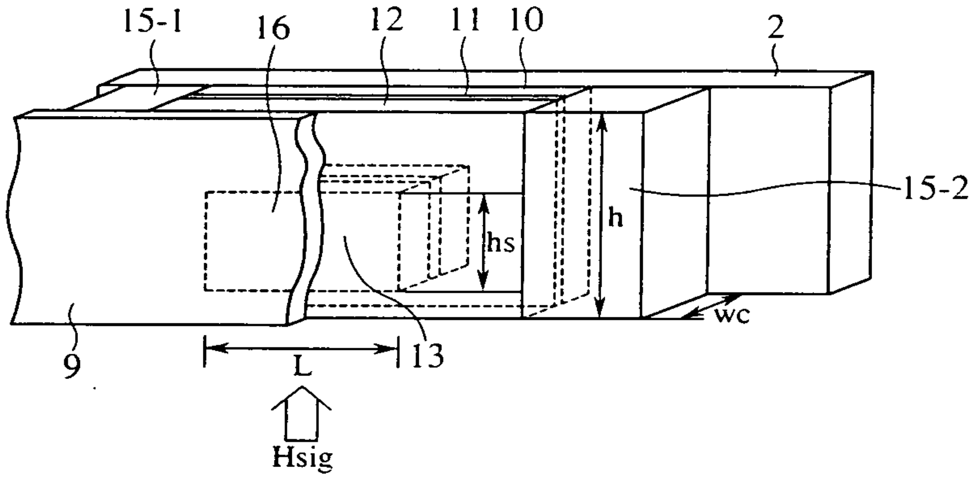

15-1
16
12
11
10
2
15-2
hs
h
wc
9
L
13
Hsig

FIG. 7B

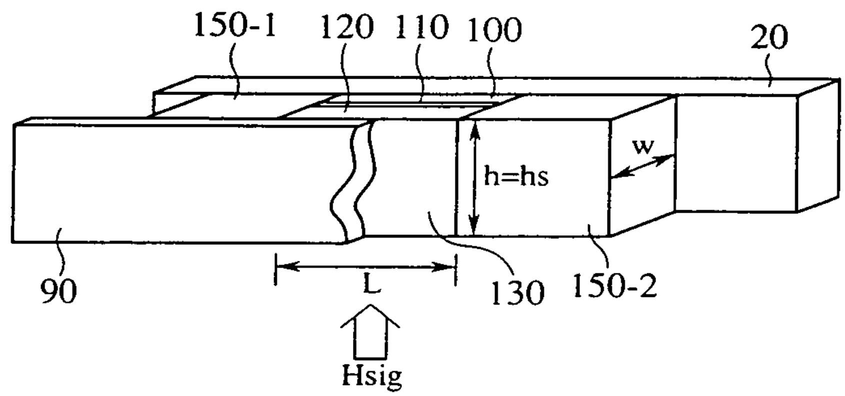

150-1
120
110
100
20
w
h=hs
90
L
130
150-2
Hsig

FIG. 8

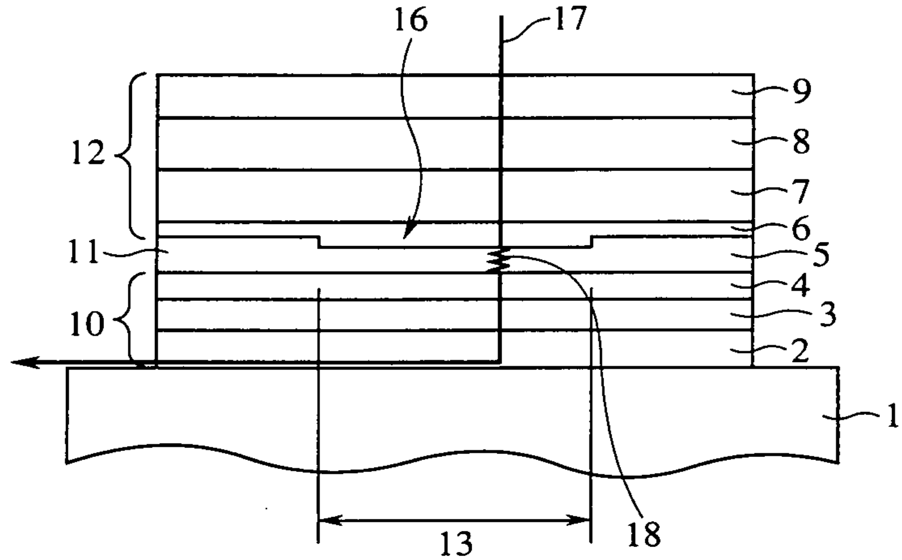


FIG. 9A

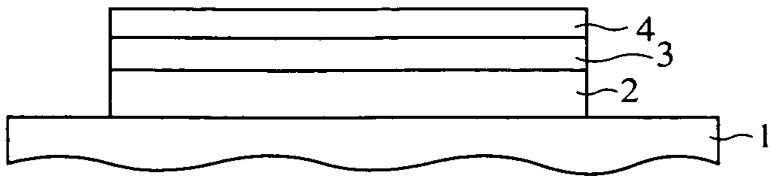


FIG. 9B

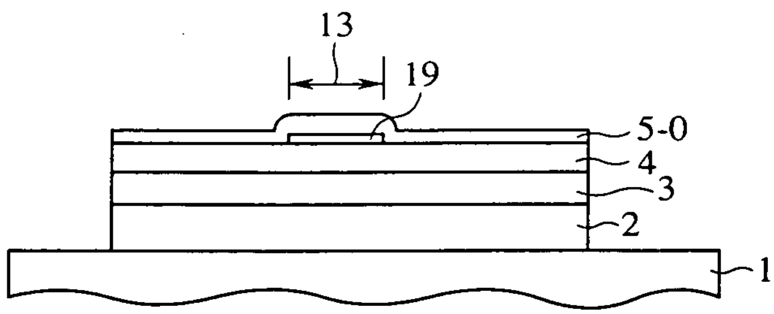


FIG. 9C

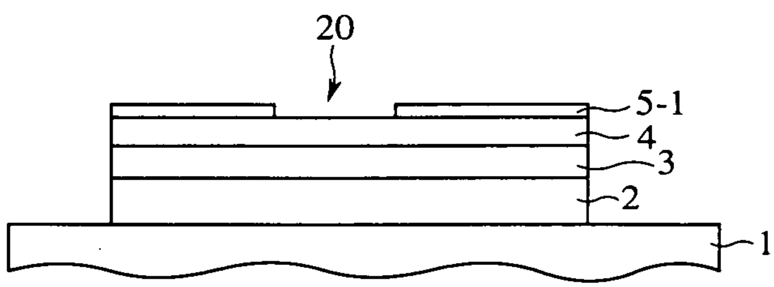


FIG. 9D

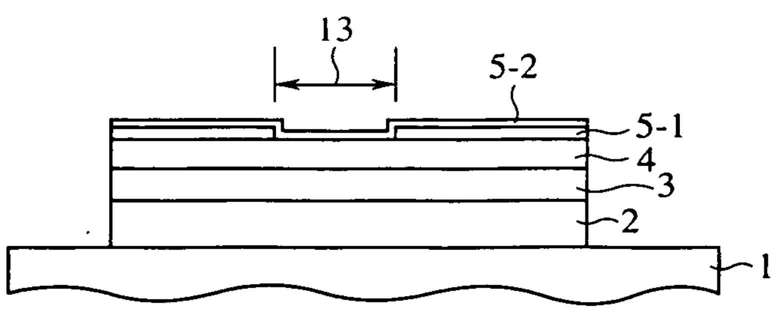


FIG. 10A

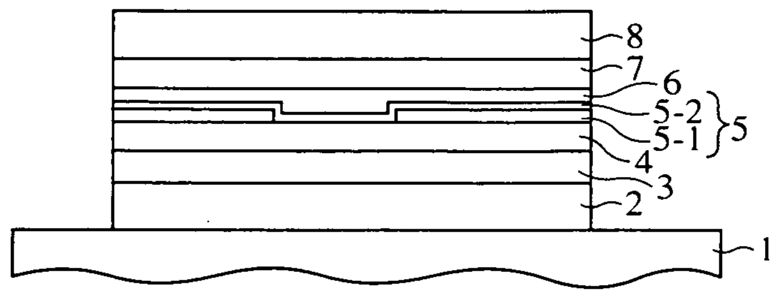


FIG. 10B

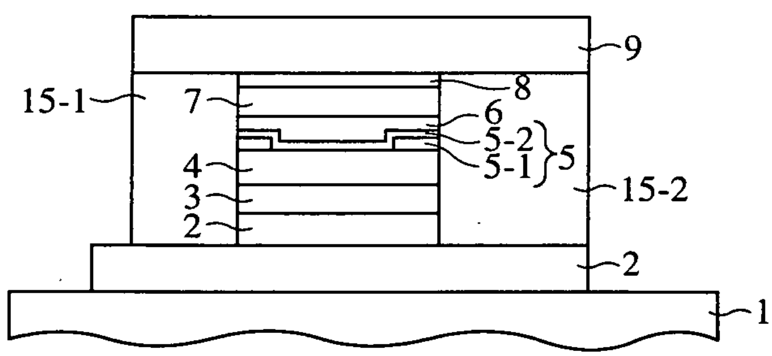


FIG. 10C

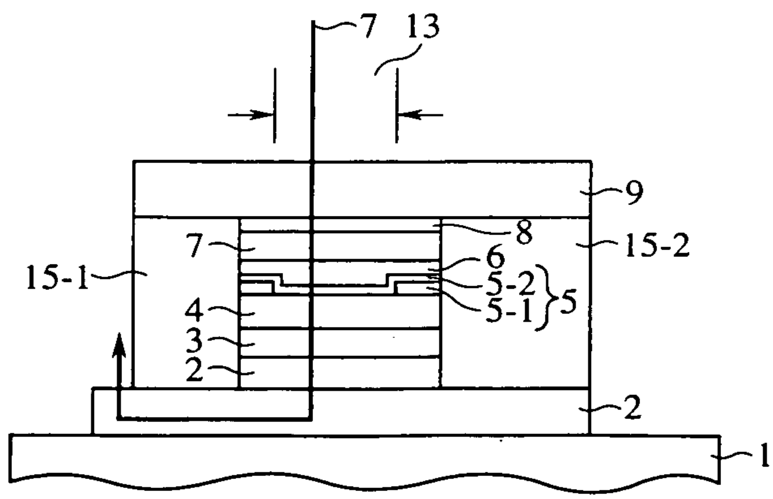


FIG. 11A

FIG. 11B

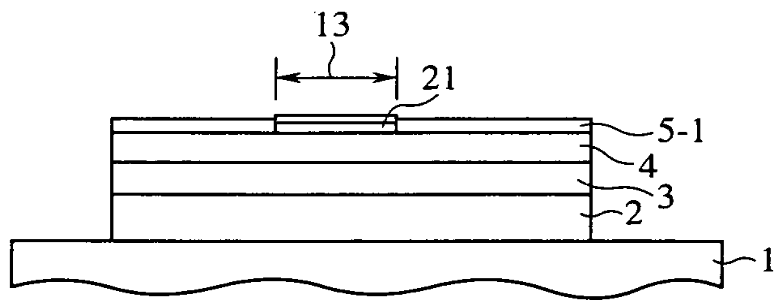


FIG. 11C

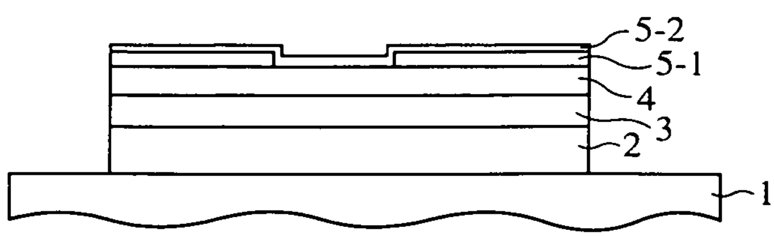


FIG. 12A

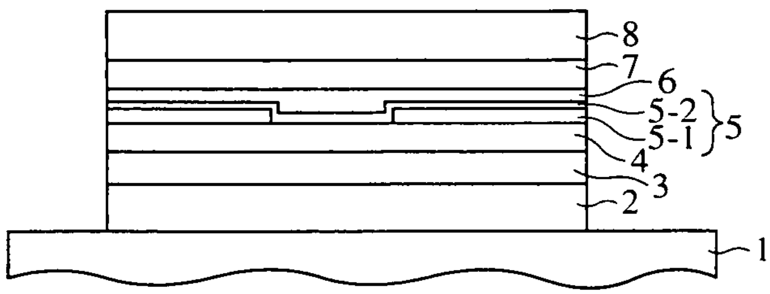


FIG. 12B

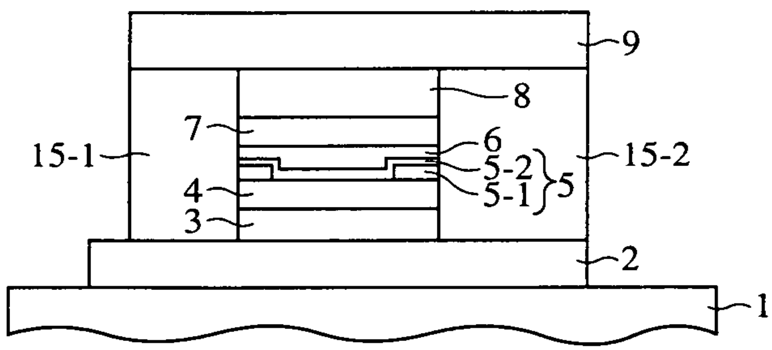


FIG. 12C

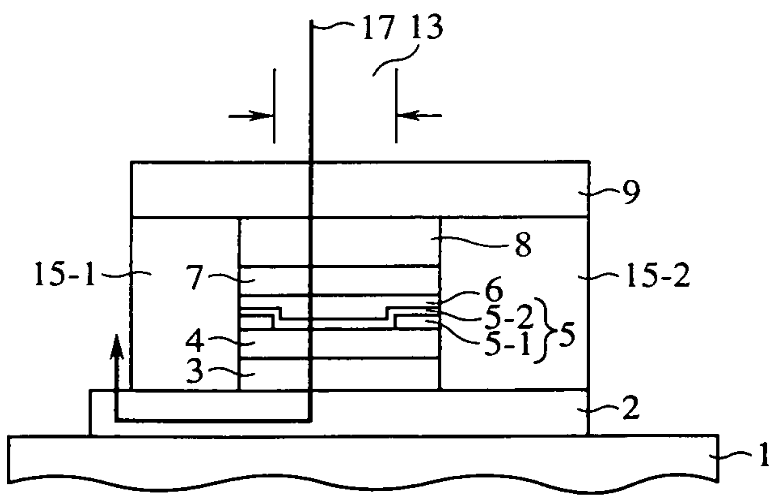


FIG. 13A

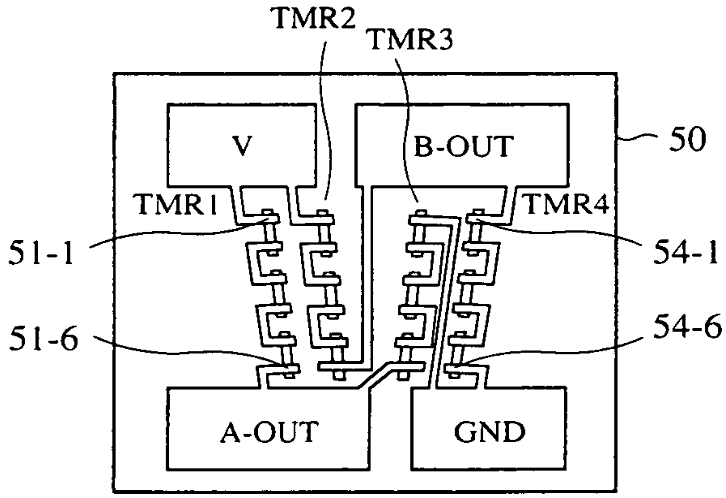


FIG. 13B

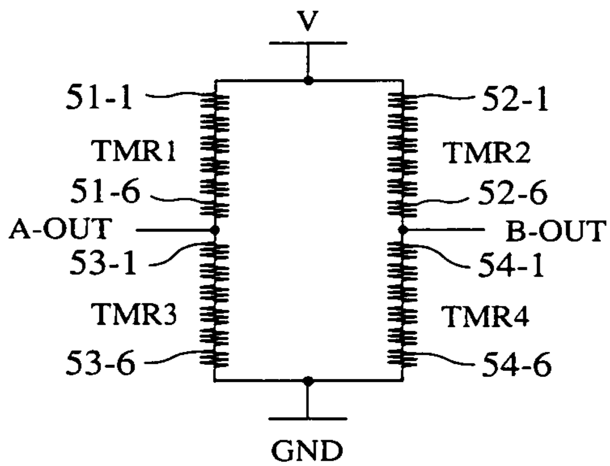


FIG. 13C

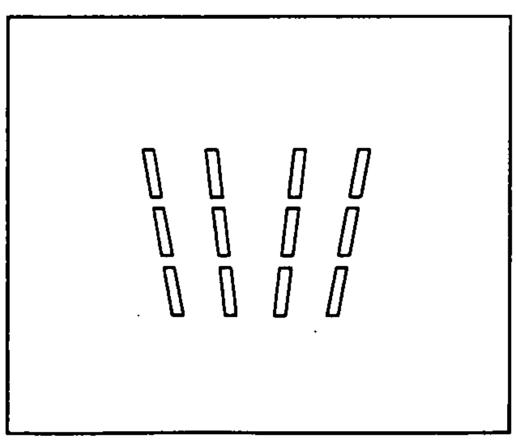


FIG. 14A

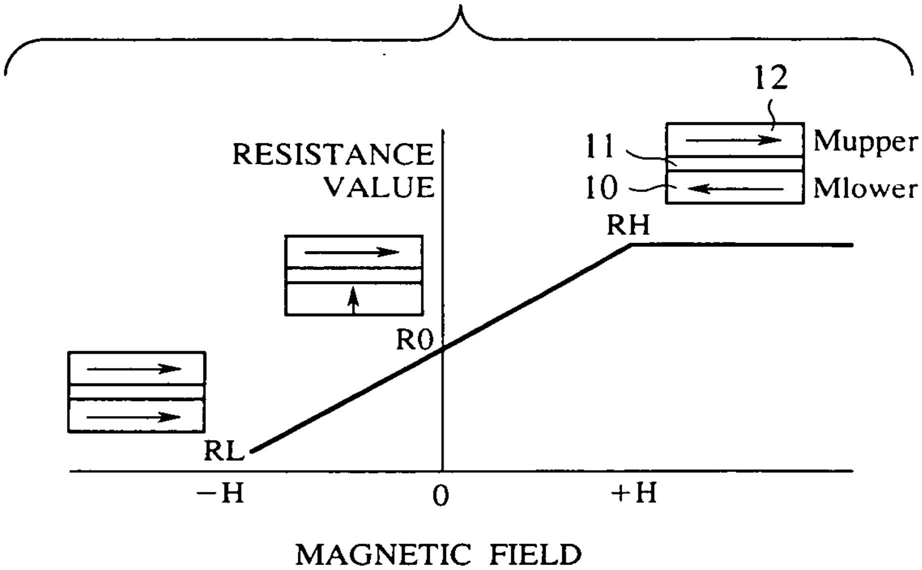


FIG. 14B

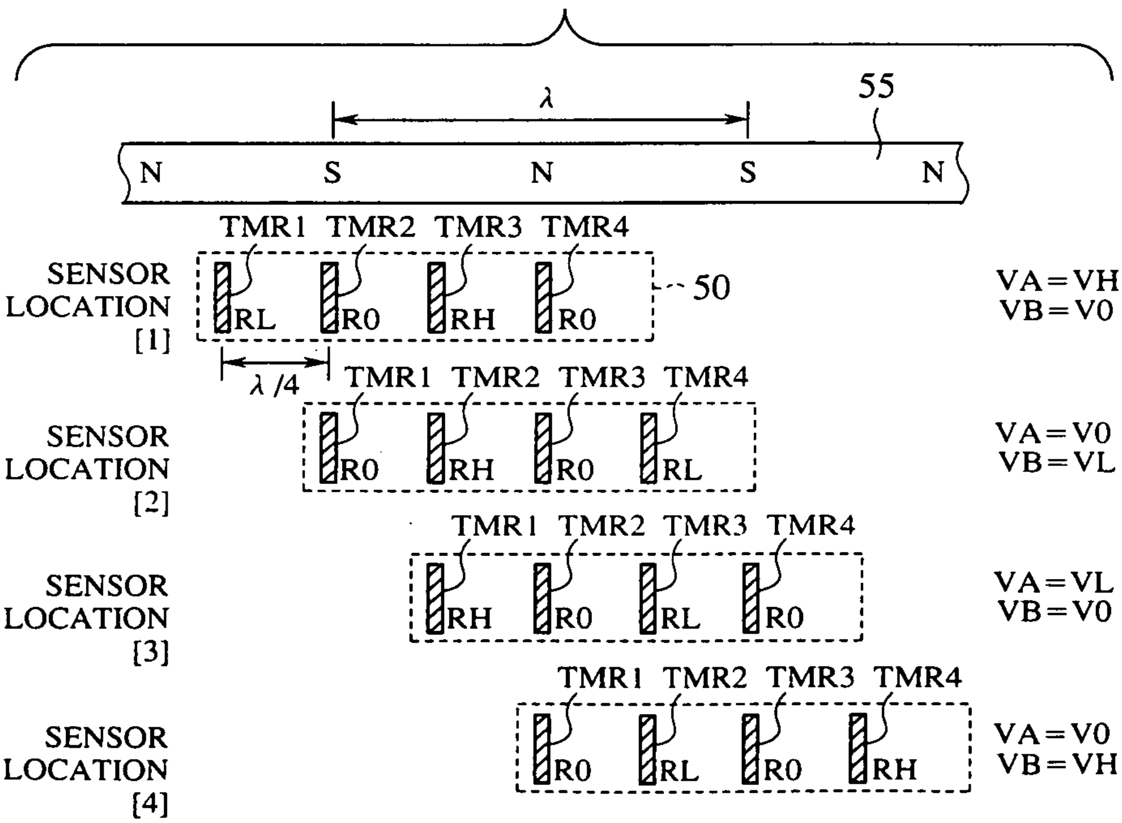


FIG. 15A

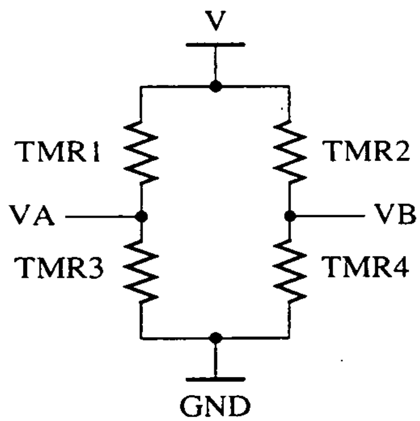


FIG. 15B

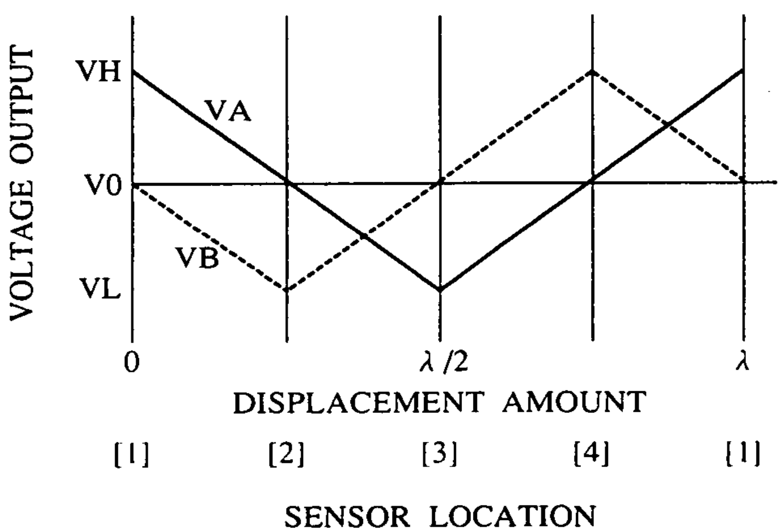


FIG. 16A

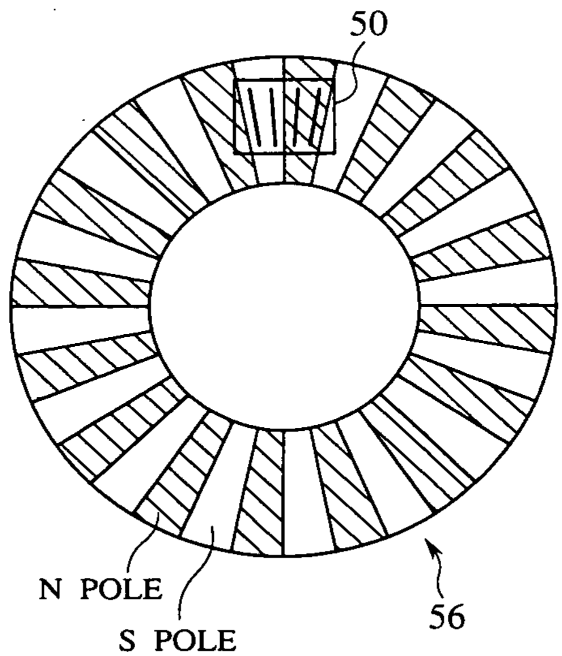


FIG. 16B

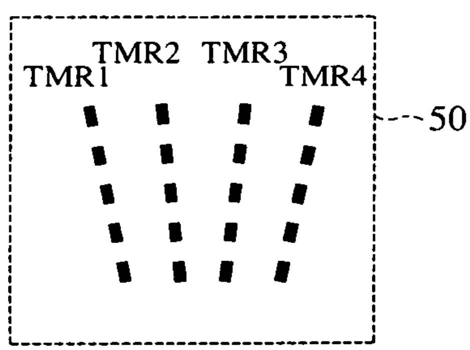


FIG. 17A

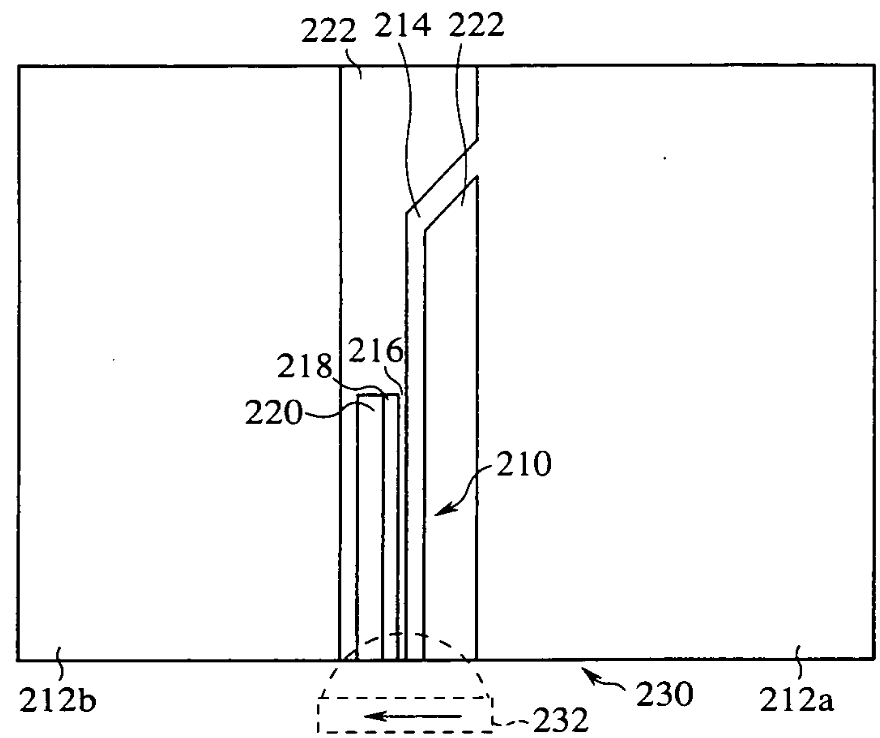


FIG. 17B

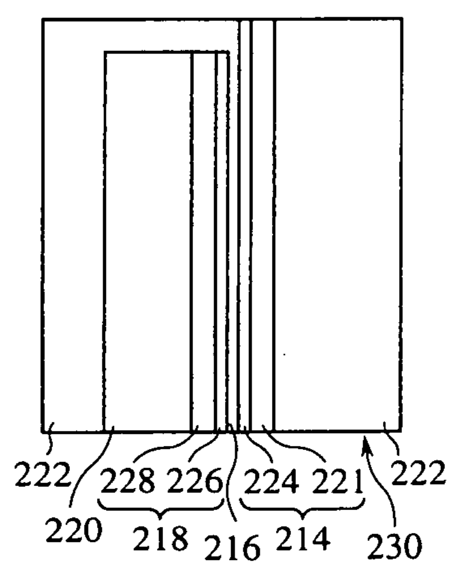


FIG. 18

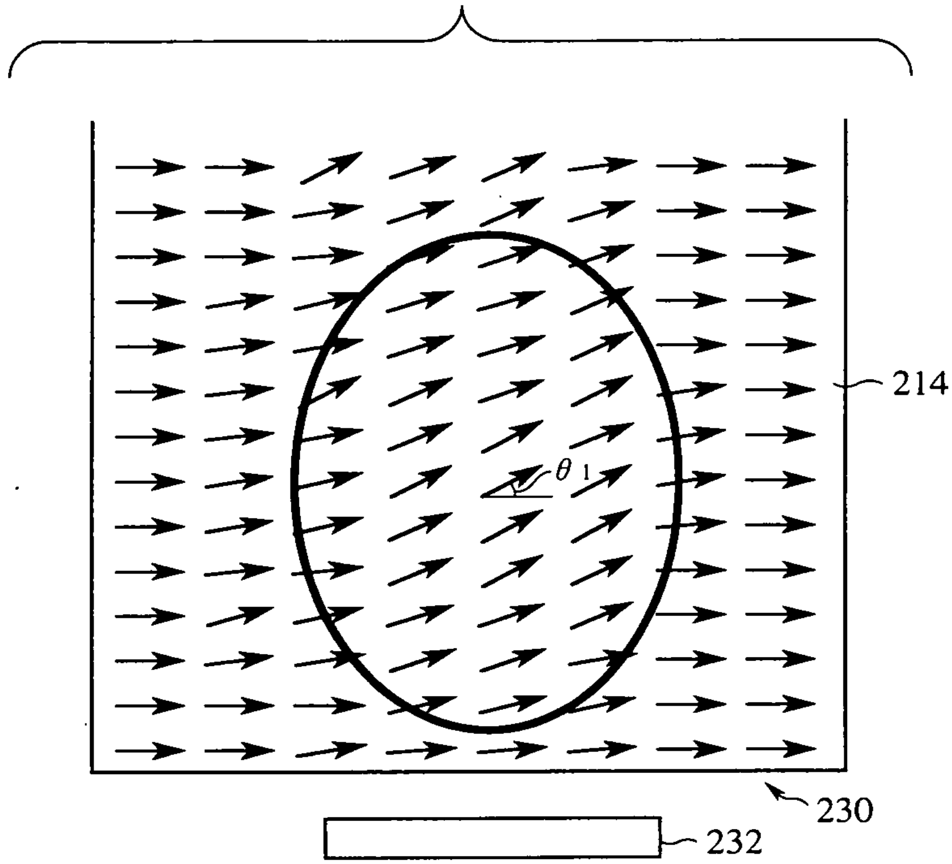


FIG. 19A

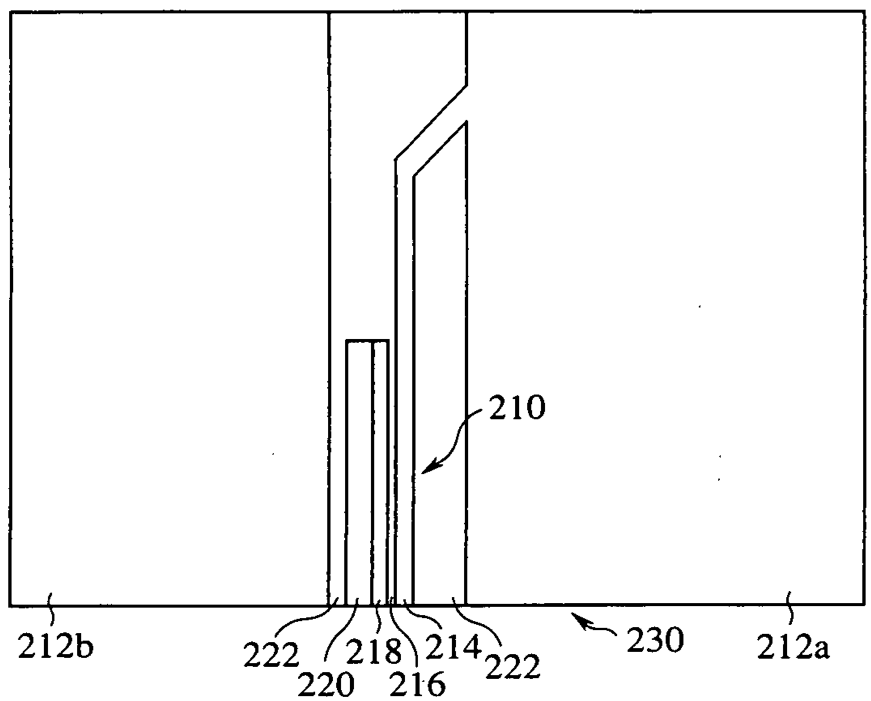


FIG. 19B

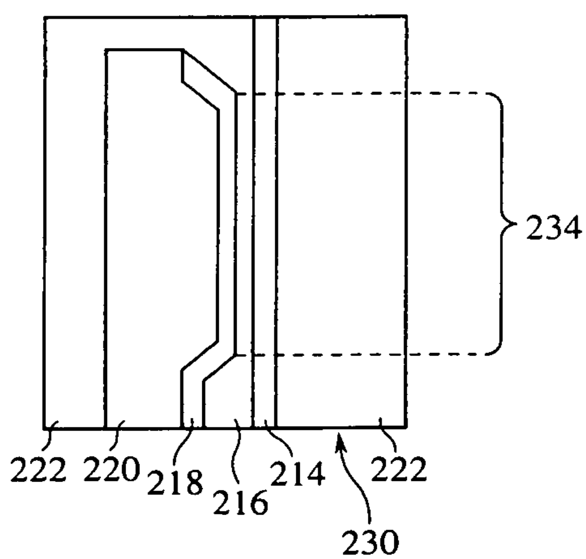


FIG. 20

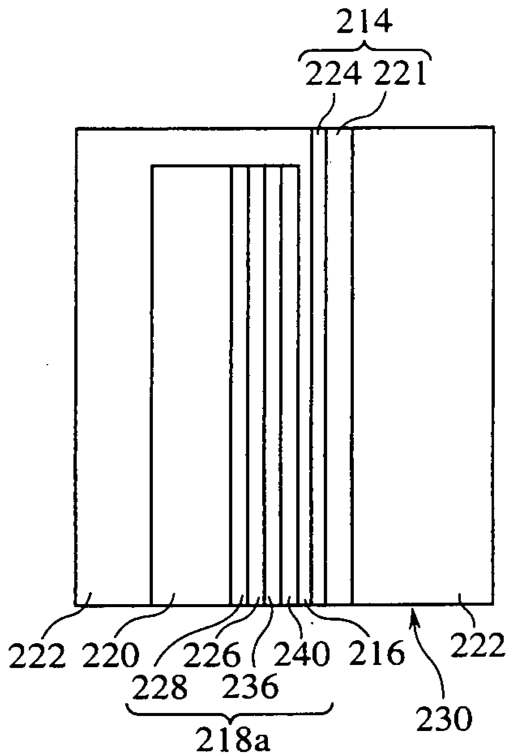


FIG. 21A

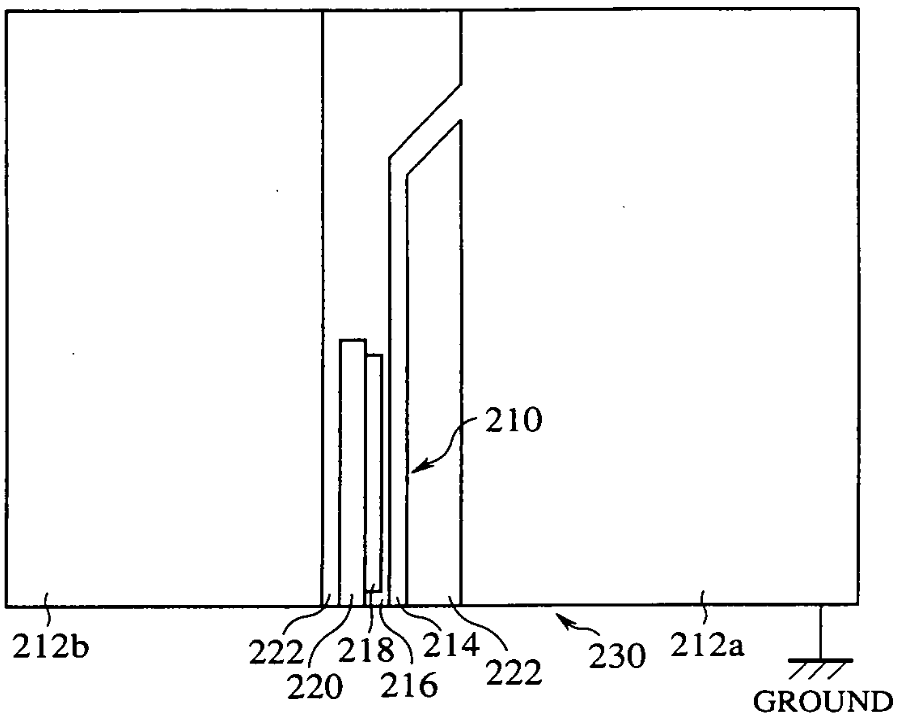


FIG. 21B

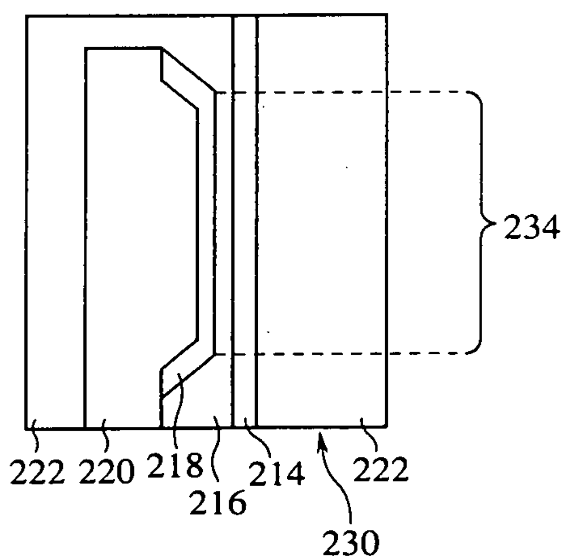


FIG. 22

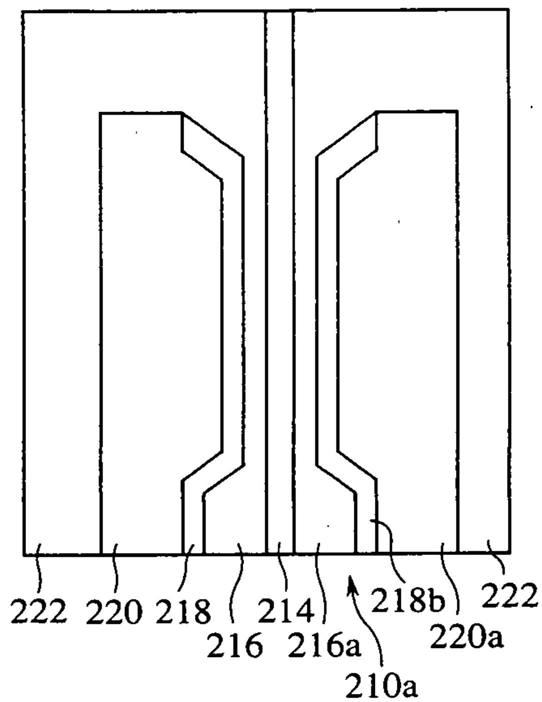


FIG. 23

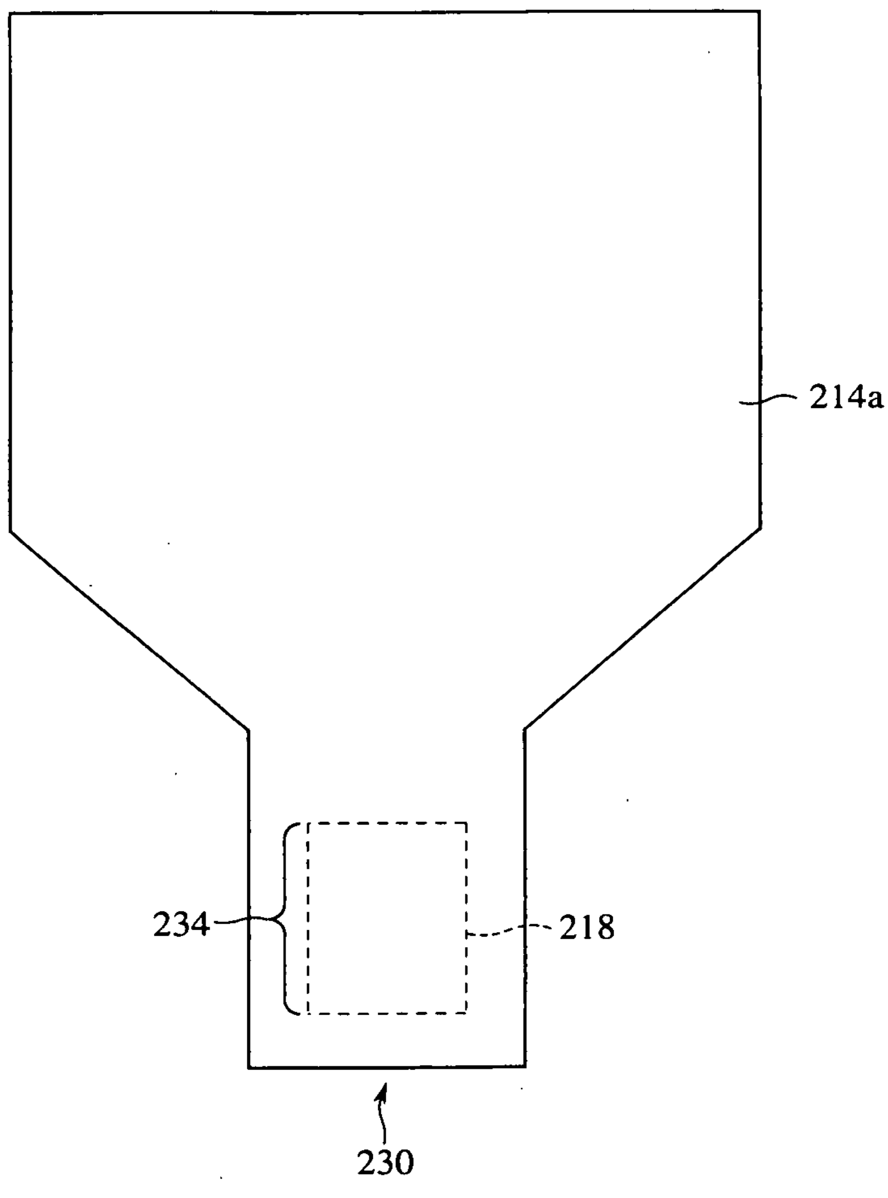


FIG. 24

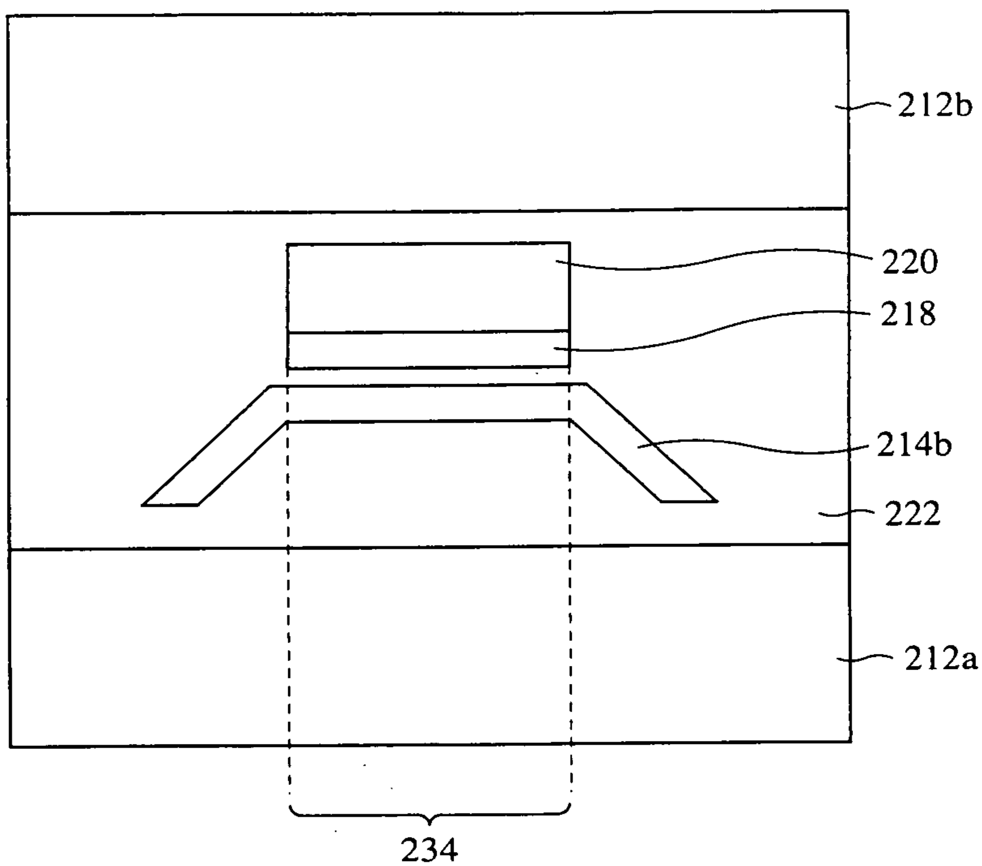
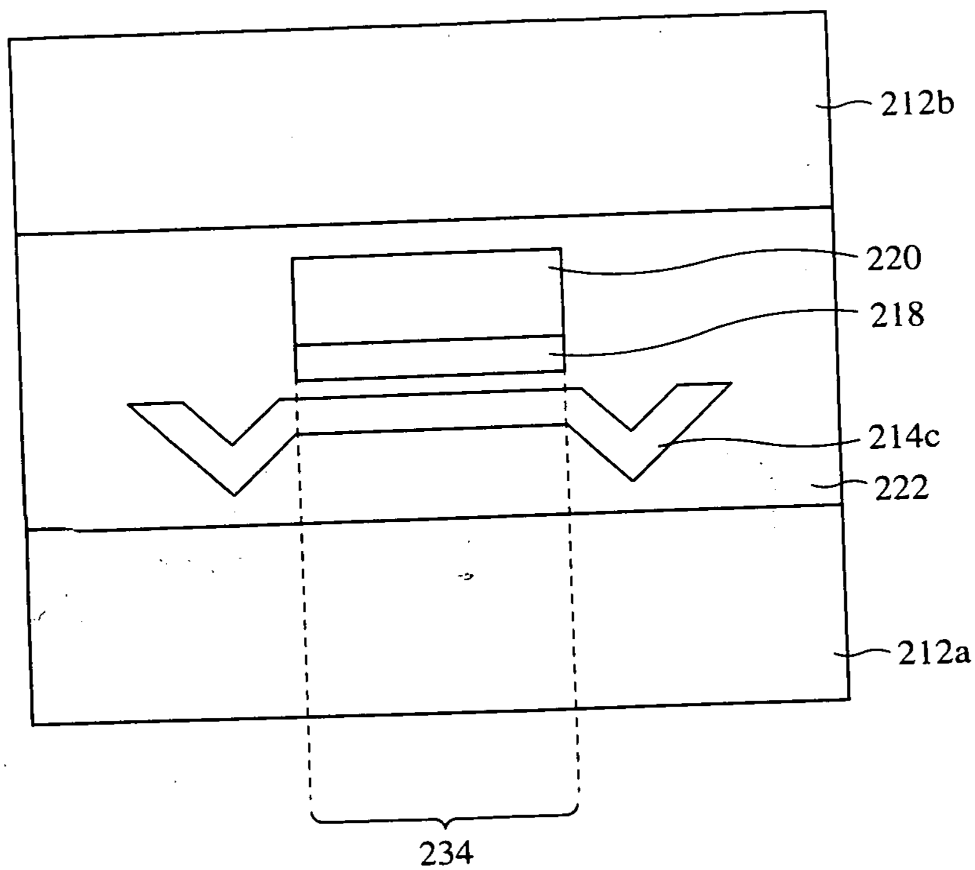


FIG. 25



PTO/SB/106 (8-96)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Declaration and Power of Attorney For Patent Application

特許出願宣言書及び委任状

Japanese Language Declaration

日本語宣言書

下記の氏名の発明者として、私は以下の通り宣言します。

As a below named inventor, I hereby declare that:

私の住所、私書箱、国籍は下記の私の氏名の後に記載された通りです。

My residence, post office address and citizenship are as stated next to my name.

下記の名称の発明に関して請求範囲に記載され、特許出願している発明内容について、私が最初かつ唯一の発明者（下記の氏名が一つの場合）もしくは最初かつ共同発明者であると（下記の名称が複数の場合）信じています。

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled

MAGNETIC SENSOR, MAGNETIC HEAD,
MAGNETIC ENCODER AND HARD DISK DEVICE

上記発明の明細書（下記の欄でx印がついていない場合は、本書に添付）は、

the specification of which is attached hereto unless the following box is checked:

☐ ＿月＿日に提出され、米国出願番号または特許協定条約国際出願番号を＿＿＿＿とし、（該当する場合）＿＿＿＿に訂正されました。

☒ was filed on June 12, 2000 as United States Application Number or PCT International Application Number 09/581,468 and was amended on ＿＿＿＿ (if applicable).

私は、特許請求範囲を含む上記訂正後の明細書を検討し、内容を理解していることをここに表明します。

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

私は、連邦規則法典第37編第1条56項に定義されるとおり、特許資格の有無について重要な情報を開示する義務があることを認めます。

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56.

Japanese Language Declaration
(日本語宣言書)

私は、米国法典第３５編１１９条(a)-(d)項又は３６５条(b)項に基き下記の、米国以外の国の少なくとも一ヵ国を指定している特許協力条約３６５(a)項に基ずく国際出願、又は外国での特許出願もしくは発明者証の出願についての外国優先権をここに主張するとともに、優先権を主張している、本出願の前に出願された特許または発明者証の外国出願を以下に、枠内をマークすることで、示しています。

I hereby claim foreign priority under Title 35, United States Code, Section 119 (a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application(s)
外国での先行出願

(Number) (番号)	(Country) (国名)	(Day/Month/Year Filed) (出願年月日)	Priority Not Claimed 優先権主張なし
10-289781	Japan	October 12, 1998	☐
10-308989	Japan	October 29, 1998	☐

私は、第３５編米国法典１１９条(e)項に基いて下記の米国特許出願規定に記載された権利をここに主張いたします。

I hereby claim the benefit under Title 35, United States Code, Section 119(e) of any United States provisional application(s) listed below.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Application No.) (出願番号)	(Filing Date) (出願日)

私は、下記の米国法典第３５編１２０条に基いて下記の米国特許出願に記載された権利、又は米国を指定している特許協力条約３６５条(c)に基ずく権利をここに主張します。また、本出願の各請求範囲の内容が米国法典第３５編１１２条第１項又は特許協力条約で規定された方法で先行する米国特許出願に開示されていない限り、その先行米国出願書提出日以降で本出願書の日本国内または特許協力条約国際提出日までの期間中に入手された、連邦規則法典第３７編１条５６項で定義された特許資格の有無に関する重要な情報について開示義務があることを認識しています。

I hereby claim the benefit under Title 35, United States Code, Section 120 of any United States application(s), or 365(c) of any PCT international application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT international application in the manner provided by the first paragraph of Title 35, United States Code Section 112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations, Section 1.56 which became available between the filing date of the prior application and the national or PCT international filing date of application.

(Application No.) (出願番号)	(Filing Date) (出願日)	(Status: Patented, Pending, Abandoned) (現況：特許許可済、係属中、放棄済)
PCT/JP99/05568	Oct. 8, 1999	Pending

私は、私自身の知識に基ずいて本宣言書中で私が行なう表明が真実であり、かつ私の入手した情報と私の信じるところに基ずく表明が全て真実であると信じていること、さらに故意になされた虚偽の表明及びそれと同等の行為は米国法典第１８編第１００１条に基ずき、罰金または拘禁、もしくはその両方により処罰されること、そしてそのような故意による虚偽の声明を行なえば、出願した、又は既に許可された特許の有効性が失われることを認識し、よってここに上記のごとく宣誓を致します。

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

PTO/SB/106 (8-96)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office; U.S. DEPARTMENT OF COMMERCE

Japanese Language Declaration
(日本語宣言書)

委任状： 私は下記の発明者として、本出願に関する一切の手続きを米特許商標局に対して遂行する弁理士または代理人として、下記の者を指名いたします。（弁理士、または代理人の氏名及び登録番号を明記のこと）

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith *(list name and registration number)*

Attorney	Reg. No.	Attorney	Reg. No.
Patrick G. Burns	29,367	James K. Folker	37,538
Roger D. Greer	26,174	Jonathan D. Feuchtwang	41,017
Lawrence J. Crain	31,497	B. Joe Kim	41,895
Steven P. Fallon	35,132	Carole A. Mickelson (Agent)	30,778
Paul G. Juettner	30,270		

直接電話連絡先：（名前及び電話番号）

Send Correspondence to:
Direct Telephone Calls to: *(name and telephone number)*
Patrick G. Burns, Esq.
Greer, Burns & Crain, Ltd.
Sears Tower- Suite 8660
233 S. Wacker Drive
Chicago, IL 60606 (312) 993-0080

唯一または第一発明者名	Full name of sole or first inventor Masashige Sato
発明者の署名 日付	Inventor's signature Masashige Sato Date 2001. 7. 3
住所	Residence Japan
国籍	Citizenship Japan
私書箱	Post Office Address c/o Fujitsu Limited
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第二共同発明者	Full name of second joint inventor, if any Hideyuki Kikuchi
第二共同発明者 日付	Second inventor's signature Hideyuki Kikuchi Date 2001. 7.3
住所	Residence Japan
国籍	Citizenship Japan
私書箱	Post Office Address c/o Fujitsu Limited
	1-1,Kamikodanaka 4-chome, Nakahara-ku, Kawasaki-shi, Kanagawa 211-8588 Japan

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発明者の署名 日付	Inventor's signature Kazuo Kobayashi Date ~~Jun 4, 2001~~ K.K. July 4, 2001
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第二共同発明者 日付	Inventor's signature Date
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唯一または第一発明者名	Full name of fifth joint inventor, if any
発明者の署名 日付	Inventor's signature Date
住所	Residence
国籍	Citizenship
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第二共同発明者	Full name of sixth joint inventor, if any
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住所	Residence
国籍	Citizenship
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（第三以降の共同発明者についても同様に記載し、署名をすること） (Supply similar information and signature for third and subsequent joint inventors.)